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Army Aeromedical Research Laboratory
Fort Rucker, Alabama

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December 1975

Final Report

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Aviators were required to fly a UH-1 helicopter at night with and without night vision goggles (AN/PVS-5). Three types of goggles were used: 40° field-of-view (FOV), 60° FOV, and 40° FOV with a 30% bifocal cut. During flight, data was acquired on over twenty aircraft status and control input variables. These data, for purposes of performance comparison, were subjected to both univariate and multivariate analyses. The six subjects (instructor pilots) also responded to a questionnaire regarding preference, trai

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SUMMARY

Aviators were required to fly a UH-1 helicopter at night with and without night vision goggles (AN/PVS-5). Three types of goggles were used: 40° field-of-view (FOV), 60° FOV, and 40° FOV with a 30% bifocal cut. During flight, data was acquired on over twenty aircraft status and control input variables. These data, for purposes of performance comparison, were subjected to both univariate and multivariate analyses. The six subjects (instructor pilots) also responded to a questionnaire regarding preference, training and estimated capabilities of each type intensification system. The major finding of both the subjective and objectives measures are provided.

Approved:

ROBERT W. BAILEY
Colonel, MSC
Commanding

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INTRODUCTION

Throughout the ages, man's capability to carry cut continuous military operations has been in part limited by his ability to function effectively at night. Current U. S. Army doctrine emphasizes the need to expand aviation operations to a 24-hour capability. Two approaches are being pursued in an attempt to effectively extend aviation operations into the night. One approach concerns the development of techniques to train aviators to fly with the unaided eye while the other approach concerns the utilization of devices which enhance night vision. One such device, the AN/PVS-5 night vision goggles (NVG), amplifies existing ambient light thus intensifying the images presented to the eye.

The AN/PVS-5 goggles were originally developed for ground use but are now considered to be an interim solution to aid the pilot's night vision. With one exception,[17] previous research projects utilizing the NVG's in the airborne setting have not directly addressed evaluation of helicopter flight performance with and without the aid of the NVG's.[1,12,13,14] These projects have examined helicopter flight performance with the aid of the NVG's only as an adjunct to other tactical field tests. Therefore, statements concerning the effectiveness of the NVG's in relation to flight performance have been limited, typically, to subjective impressions which often reflect a bias from other experimental treatments involved in the field tests. The findings of these projects have provided, in several cases, contradictory comments about the capabilities produced by the NVG's. Much of the conflict concerning the utility of the NVG's stems from the fact that the effectiveness of the goggles varies greatly according to the: (1) existing ambient light levels, (2) flight maneuvers performed, (3) altitudes (AGL) at which flights are made, (4) aircraft flown, (5) amount of training the pilots have received with the NVG's, and (6) whether or not bright external lights are present, such as flares, which cause temporary problems with the NVG's and degrade the dark adaptation of the unaided eye.

Combat Development Command (CDEC) project 43.7, Phase I, found that "the NVG, tested in all tactical modes, appeared to assist the crew in flying with greater safety at low altitudes at a slightly greater airspeed."[12] The objective of the project was not to directly examine helicopter flight performance, but to "establish the state-of-the-art of helicopter anti-tank operations under clear night conditions, to develop aviator training requirements for this type experiment, and to identify problem areas for night operations."[12] The report also pointed out that "NOE [nap-of-the-earth] flight under a no moonlight condition may be defined as 125 feet above tree level. Night NOE at higher

light levels can be flown at near daylight standards (fifty feet above tree or obstacle level)."[12] However, these altitudes would have to be reduced in flat terrain areas to prevent optical and electronic detection. Although a number of problems were noted in connection with the use of the NVG's, "their use was most desired during the lowest light level periods."[12] A very definite advantage of the NVG's noted in the CDEC report was their automatic light level regulation capability. Thus, flares and illumination rounds only momentarily disrupt vision with the NVG's while sometimes causing a significant degradation of dark adaptation in the unaided eye.

Modern Army Selected Systems Test Evaluation and Review (MASSTER) Test Number 10-40 also evaluated the NVG's in an airborne setting.[1,14] This test examined the AN/PVS-5 night vision goggles along with other flight related items of equipment in tactical situations. Again aviator flight performance was not directly examined, but inferences were made about the performance enhancement the NVG's provided. "When flares and other bright light sources such as rocket motor-burn, vehicle headlights, etc., were encountered, the AN/PVS-5 goggles were superior to unaided eyes. . .When using the goggles, the crew experienced no loss of night vision and was able to see clearly as soon as the light source was out of the field-of-view. This allowed the pilots who were using the goggles to fly much lower, faster, and safer than the crews who were not using them."[1]

The Military Airlift Command operationally examined the AN/PVS-5 40° field-of-view NVG's and the older SU-50C 60° field-of-view NVG's in order to evaluate their relative potential for Local Base Rescue (LBR) use.[13] The results of the operational test and evaluation indicated "that the AN/PVS-5 NVG's were superior to the 60° field-of-view goggles and demonstrated excellent potential for the LBR mission."[13]

Land Warfare Laboratory (LWL) Report Number 74-36 did address the feasibility of using the NVG's for flying helicopters at low levels at night.[17] THe AN/PVS-5 night vision goggles were compared to two other approaches intended to enhance the pilot's visual capabilities at night: (1) the use of searchlights and the unaided eye, and (2) infrared searchlights with the AN/PVS-5 goggles. Subjective judgments of the test pilots, recorded comments during the flight and a written debriefing were used to evaluate the three approaches. "The program determined that the goggles alone were the best approach for tactical employment."[17]

Several laboratory assessments of the NVG's have been made in relation to some of the problems identified concerning their use.[2,3,4,5,6,8,11] Investigators at the U. S. Army Aeromedical Research Laboratory found that:

(1) The afterimages "Brown-Eye Syndrome" sometimes seen following use of AN/PVS-5 NVG's "are a normal physiological phenomenon and need not be of concern."[3]

(2) "Although dark adaptation is not fully degraded by the AN/PVS-5 NVG, there is some reduction and should it be necessary to remove the goggle, it will require about two minutes to reach the fully dark-adapted state."[5]

(3) Also noted was that the effect of a light source upon dark adaptation is a function of both the intensity and wavelength of the source. The suggestion was made that future NVG systems employ yellow-orange phosphors instead of the green phosphors used, in order to maximally protect dark adaptation.[5]

(4) "The use of a black background map is a suitable solution to the problem of losing information when the NVG is used."[4] The black background map produced "equally good results when viewed under red illumination with the unaided eye."[4]

(5) Changes should be considered for improvement of the crash-worthiness and comfort of the NVG's, such as moving "the vertical support straps forward to the c.g.(center of gravity) of the goggles," "decreasing the weight of the goggles as much as possible" (perhaps with a plastic lens and magnesium housing), and "strengthening the attachment of the lens to the face mask to improve the pressure distribution for crash loads."[6] Additionally, a suggestion was made "to study, design, and develop an integrated helmet-goggle system."[6]

In order to objectively evaluate the NVG's in the airborne environment, the U. S. Army Aeromedical Research Laboratory was asked to measure aviator performance using several variations of these devices in helicopter flight close to the earth at night. Current aviation tactics emphasize helicopter flight at very low altitudes (terrain flying) to avoid the threat of sophisticated air defense weapons. Terrain flying is composed of Nap-of-the-Earth (NOE), Contour, and Low Level flight profiles. These flight levels have been defined as: **NOE** - Flight as close to the earth's surface as vegetation or obstacles will permit, while generally following the contours of the earth. Airspeed and altitude are varied as influenced by the terrain, weather and enemy situation. The pilot preplans a broad corridor of operation based on known terrain features which has a longitudinal axis pointing toward his objective. In flight, the pilot uses a weaving and devious route within his preplanned corridor while remaining oriented along his general axis of movement in order to take maximum advantage of the cover and concealment afforded by terrain, vegetation and manmade features. By gaining maximum cover and concealment from enemy detection,

observation and fire power, nap-of-the-earth flight exploits surprise and allows for evasive actions. CONTOUR - Flight of low altitude conforming generally, and in close proximity to the contours of the earth. This type of flight takes advantage of available cover and concealment in order to avoid observation or detection of the aircraft and/or its points of departure and landing. It is characterized by a constant airspeed and a varying altitude as vegetation and obstacles dictate. LOW LEVEL - Flight conducted at a selected altitude at which detection or observation of the aircraft is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant airspeed and indicated altitude. This method is best adapted to flights conducted over distances or periods of time.

The purpose of the present investigation was to evaluate the flight performance of aviators during NOE flight (without navigation), low level flight and four standard maneuvers while using three configurations of the NVG's and the dark-adapted unaided eye.

METHOD

Subjects: Subjects for this investigation were six rotary wing Army aviators assigned to the Advanced Tactics Division, Department of Flight Training, U. S. Army Aviation School at Ft. Rucker. These pilots had extensive experience in rotary wing flight, having flown an average of 1960 hours in rotary wing aircraft. All were experienced in nap-of-the-earth flight and had completed the Army training on this type of flight profile. None of these aviators possessed previous experience with the night vision goggles.

Apparatus: The 40° and 60° field-of-view (FOV) and 40° FOV bifocals (40°b) night vision goggles were made available by the Night Vision Laboratory. The NVG's are self-contained, battery powered, second generation, passive, binocular devices. The upper 70% of the lense on the 40°b goggles was focused at infinity while the lower 30% was focused at approximately 26 inches. The 40° and 60° FOV goggles were also focused at infinity. The NVG's weigh approximately 1.9 pounds and were mounted on the SPH-4 helmet with snaps and Velcro attachments. The test vehicle was a JUH-1H helicopter instrumented to measure and record pilot control inputs and aircraft position, rates and accelerations. This Helicopter Inflight Monitoring System (HIMS) measures aircraft position in six degrees of freedom while simultaneously recording cyclic, collective and pedal inputs and aircraft status values. These data were recorded in real time on an incremental digital recorder. Continuous information from twenty pilot and aircraft monitoring points was recorded for all flights. A list of these parameters is provided in Table 1. This table also

lists the derived measures which can be obtained from the recorded parameters.

Table 1

Parameters Measured and Derived

Parameters Measured	Derived Measures
Pitch	Pitch Rate
Roll	Roll Rate
Heading	Rate of turn
Position x	Constant Error, Average Absolute Error, RMS Error
Position y	Ground Speed, Constant Error Average Absolute Error, RMS Error
Acceleration x	
Acceleration y	
Acceleration z	
Roll Rate	Roll Acceleration
Pitch Rate	Pitch Acceleration
Yaw Rate	Yaw Acceleration
Radar Altitude	Rate of Climb, Average Absolute Error, Constant Error, RMS Error
Barometric Altitude	Rate of Climb
Airspeed	
Flight Time	
Rotor RPM	
Throttle	
Cyclic Stick (Fore-Aft) Cyclic Stick (Left-Right) Collective Pedals	Control Position, Absolute Control Movement Magnitude, Positive Control Movement Magnitude, Negative Control Movement Magnitude, Absolute Average Control Movement Rate, Average Positive Control Movement Rate, Average Negative Control Movement Rate, Control Reversals, Instantaneous Control Reversals, Control Steady State, Control Movement

Pilot inputs to controls were treated in the following manner. In considering these measures, it is necessary to define three key terms. First, in obtaining measures on these controls, it was decided that a <u>steady state</u> occurred when a control had not exceeded an empirically defined distance in a specified time. Second, a <u>control reversal</u> occurred any time a control changed direction. Finally, a <u>control movement</u> was defined as any movement starting from a steady state or control reversal and ending with a steady state or control reversal. Using these established criteria, means were computed from all sampled values for magnitude, duration and rate of control movements and mean time for steady states. The totals for number of steady states and control movements were also recorded. Table 2 presents the times and distances which were utilized as criteria delineating movements in these controls.

The distance ranges were established by determining the minimum perceived control movement for the directions of concern which were thought to yield airframe movement independent of time. The times were established by taking one-half the minimum time it took to move the various controls through the distance ranges previously established.

Table 2

Baseline Times and Movement Limits for Controls

	CYCFA	CYCLR	COLL	THROTTLE	PEDAL
Time durations in seconds	.25	.15	.45	.50	.50
Movement limits in inches	.37	.32	.35	.50	.35

A more detailed description of HIMS can be found in USAARL Report No. 72-11.[7] A questionnaire was also constructed to determine the aviators' opinions about the night vision goggles as related to five general categories: (1) comparison of the two NVG's fields-of-view, (2) flight maneuvers, (3) psychophysiological effects, (4) equipment considerations, and (5) academic/flight training.

PROCEDURE

Familiarization and Training Phase. Since these aviators had no previous experience with the NVG's, all were trained in their use according to the following schedule. Three subjects were provided with NVG simulators and given thirty minutes flight training. During this training they were instructed in how to attach the device to their helmet, shown the various features of the device and allowed to fly different maneuvers while wearing the simulators. An attempt was made to program this period of training so that all subjects would be exposed to similar flight maneuvers as well as allowing them to gain familiarity with the goggles particular to their own needs. In order to accomplish this objective, a standard set of practice maneuvers was performed at least twice by all aviators during the allotted training period. This set of maneuvers is listed in Table 3.

Table 3

Standard Flight Maneuvers

1. Pick up to 3-foot hover
2. Perform a 360° left pedal turn
3. At 3 feet AGL, hover forward (approximately 60 feet) to a predetermined point and set the aircraft down
4. Pick the aircraft up to a 25-foot AGL hover and maintain this hover for 60 seconds
5. Descend to touchdown
6. Pick up to a 5-foot hover
7. Hover rearward to the starting point
8. Set the aircraft down

Three subjects received no simulator training, but were brought into the laboratory, given an introduction to the NVG's and allowed to familiarize themselves with the goggles in a darkened room for thirty minutes. These individuals were taught how to attach the goggles to their helmets and to adjust and focus them. They were then allowed to walk around and view different objects in the room.

All subjects received night flight training with the goggles. Order effect was controlled across subjects according to the schedule presented in Table 4. All pilots received 65 minutes of night training and testing. The same programmed set of maneuvers referenced in Table 3 was accomplished with the unaided eye and each type of NVG for all subjects during the night training period.

Table 4

Standard Maneuver
Training and Testing Schedule

S_1	Eye-X	40°-X	40°-*	40°-X	60°-X	60°-*	60°-X	40°b-X	40°b-*	40°b-X
S_2	Eye-X	40°b-X	40°b-*	40°b-X	40°-X	40°-*	40°-X	60°-X	60°-*	60°-X
S_3	Eye-X	60°-X	60°-*	60°-X	40°b-X	40°b-*	40°b-X	40°-X	40°-*	40°-X
S_4	Eye-X	40°-X	40°-*	40°-X	60°-X	60°-*	60°-X	40°b-X	40°b-*	40°b-X
S_5	Eye-X	40°b-X	40°b-*	40°b-X	40°-X	40°-*	40°-X	60°-X	60°-*	60°-X
S_6	Eye-X	60°-X	60°-*	60°-X	40°b-X	40°b-*	40°b-X	40°-X	40°-*	40°-X

X - Denotes Standard Maneuvers Test (5 minutes)
* - Denotes Practice (10 minutes)

Due to inclement weather and low ambient light levels, the LL-NOE phase of the study had to be postponed for several weeks. Because a considerable period of time elapsed between the time of initial training and the LL-NOE part of the project, the pilots were given refresher training. Each aviator received a twenty minute flight with the goggles during which he was allowed to perform maneuvers which he felt would increase his proficiency.

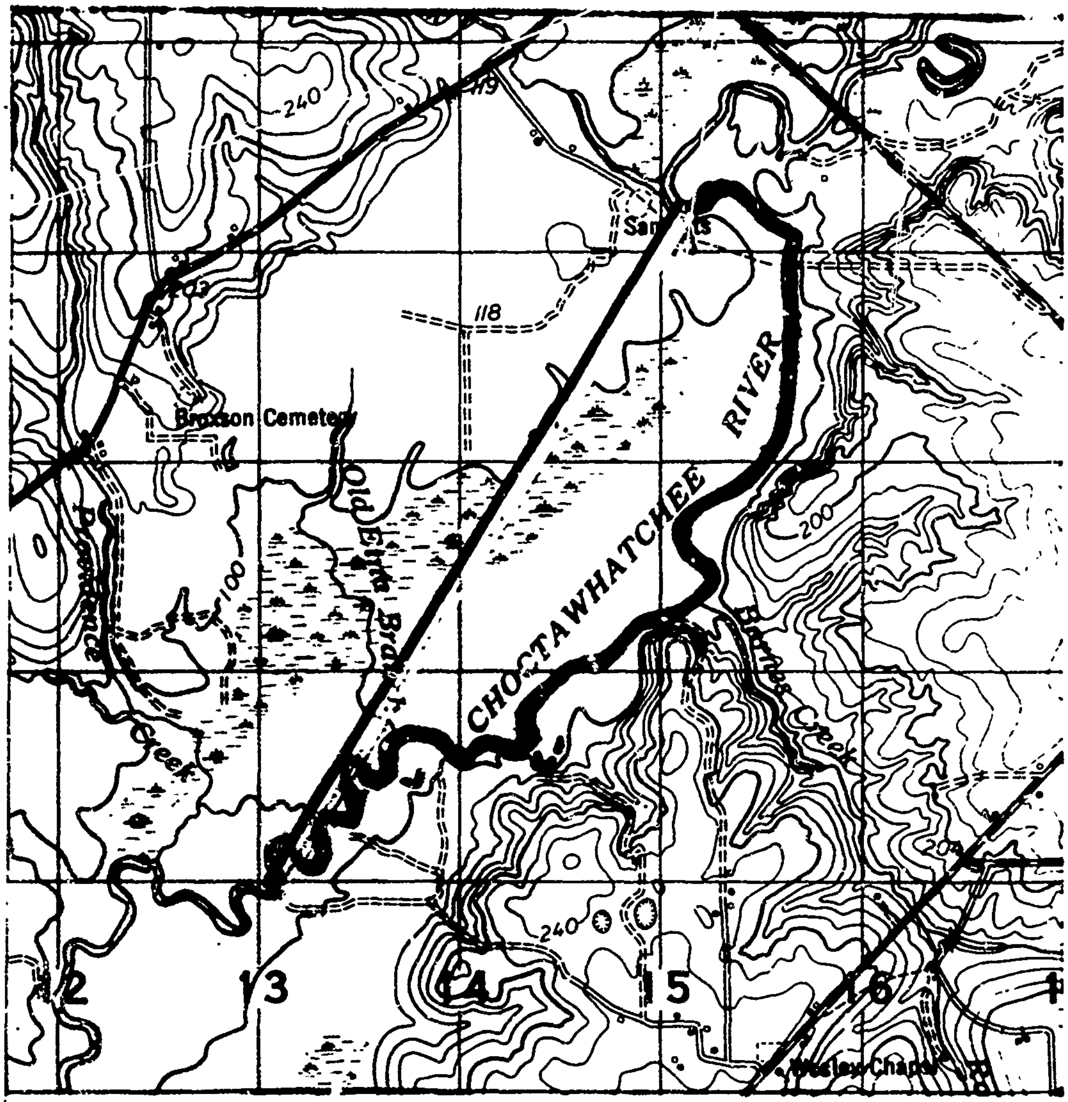
Low Level - NOE Phase. The LL-NOE phase of this study consisted of both day and night flights. A day orientation flight was first flown by the Safety IP, followed by a familiarization flight by the subject aviator at approximately 200-feet AGL, and then a final LL-NOE flight over the same course at an altitude and airspeed selected by the subject aviators. The aviators were told to choose an altitude and airspeed, for the final day and all night LL-NOE flights, commensurate with safety, but also maintaining maximum masking during the flights. The NOE and low level courses are presented in Figure 1. During testing, each pilot mounted and focused the goggles and flew the low level course and then entered the riverbed and returned on the NOE section of the mission. The low level course terrain was primarily densely wooded areas (trees approximately 60-feet tall) with occasional open fields. The NOE course was a segment of the Choctawhatchee River which was typically wide enough for the helicopter rotor blades to be below the tops of the trees that lined the river. The trees along the NOE course ranged in height from 75 to 95 feet above the river.

All subjects were required to fly the course five times at night according to the schedule referenced in Table 5. One flight was made with the unaided eye for familiarization with the course under night conditions followed by four flights, one each with each type of NVG and one dark-adapted unaided eye.

Table 5

Night
LL-NOE Flight Schedule

$Subject_1$	Eye	40°	60°	40°b	Eye
$Subject_2$	Eye	40°b	40°	60°	Eye
$Subject_3$	Eye	60°	40°b	40°	Eye
$Subject_4$	Eye	40°	60°	40°b	Eye
$Subject_5$	Eye	40°b	40°	60°	Eye
$Subject_6$	Eye	60°	40°b	40°	Eye



NOE COURSE
LOW LEVEL COURSE
SCALE 1:50,000
CONTOUR INTERVAL 20 FEET

NOE AND LOW LEVEL COURSES USED FOR EVALUATION OF THE NVG

FIGURE 1

Illuminance measurements were taken during the time periods of these flights utilizing a Spectra-Pritchard Photometer with Cosine integrator. The time periods for each flight and their respective illuminance levels are presented in Table 6. Also noted are equivalent percentages of moon illumination for the relative illuminance levels presented.

Table 6

Light Levels Measured and Derived

No. of Ss	Date	Time	Percentage of Moon Illuminated	Mean Illuminance Measured	Moon Equivalent Computed*
2	31 May	2100-2430	.76	7.20×10^{-3} ft-c	≈ 3/8
2	1 June	2100-2445	.84	5.92×10^{-3} ft-c	≈ 2/8
2	2 June	2110-0130	.91	13.9×10^{-3} ft-c	≈ 5/8

*Full Moon = 2×10^{-2} ft-c[9,10]
1/2 moon = 1×10^{-2} ft-c
1/4 moon = 5×10^{-3} ft-c
No moon = 2×10^{-4} ft-c

Training was conducted in 3/4 to full moon equivalent illuminance levels.

Analysis: Separate analyses were computed for each of the flight segments and maneuvers. Univariate F values were obtained for each of the performance variables examined. A stepwise discriminant analysis program was utilized for initial evaluation of the relationship of the performance measures to visual set group separation. The five or six* most discriminating variables identified in the original stepwise discriminant analysis (based on a set of linear classification

*Six performance variables were utilized for examination in relation to the four visual sets during the four standard maneuvers. Data was lost due to a magnetic tape recorder malfunction during one aviator's NOE and low level flight thereby reducing the sample for these two flight segments to five and consequently the number of performance variables utilized to five.

functions computed by choosing the predictors in a stepwise manner) were reexamined with the stepwise discriminant analysis program without the lesser discriminating variables thus ensuring df and multivariate F ratio stability.

The output of the stepwise discriminant analysis program included a multivariate F value and a Wilk's Lambda (U-Statistic) associated with the entering of each variable into the classification function. After the last step of the program, a classification matrix was also obtained indicating the proportion of aviators statistically classified into the correct visual condition by the performance scores.

The performance measures found in the stepwise discriminant analyses to be the most discriminating among the four visual sets in each of the six flight segments were then examined in Veldman's (1967)[18] multiple discriminant analysis program.** The program computed univariate F ratios and discriminant weights for the variables, Wilks Lambda to determine the discrimination of the variables or the overall difference among the four group centroids, a chi-square approximation for the discriminant functions or roots to determine the significance of each, and total discriminatory power or estimated omega squared which gives an estimate of the percentage of the total variability in discriminant space that is relevant to group differentiation.

For interpretation purposes, the results and discussion have been divided into univariate data, multivariate data and questionnaire sections. A variable's contribution to the discrimination of a root is determined by the size of the adjusted weights relative to the other variables' weights instead of by the univariate F ratio. The univariate F ratio indicates the discrimination a variable has among the groups when examined individually and does not necessarily demonstrate the variable's importance when combined with the other variables in a discriminant root. Primary contributors to a root were considered to be those variables whose weights (absolute values) were no less than approximately one-half the weight of the largest contributor.

**Since the flight performance for each aviator was examined under all four visual sets or experimental treatments, a technique developed by Schori and Tindall (1972) was implemented in order to ensure that the data obtained from this repeated measures design were compatible with assumptions associated with the conventional multiple discriminant analysis programs employed.[15] Reference Appendix B for additional information related to the repeated measures design.

RESULTS AND DISCUSSION

A. Univariate Data*

1. NOE Flight

Figures 2 through 6 show the means for the six performance measures which exhibited significant ($p<.05$) univariate F ratios for the NOE flight segment. Figure 2 illustrates the difference ($F = 4.33$, $df = 3/16$, $p<.05$) found in airspeed among the visual conditions during NOE flight, with the unaided eye condition having a faster airspeed than the three goggle conditions. Figure 3 depicts the number of cyclic fore-aft control movements made by the four groups with the 40° goggle set having the highest number and the unaided eye condition the least ($F = 8.85$, $df = 3/16$, $p<.01$). The 40° goggles also produced the highest number of cyclic left-right control movements (Figure 3) while the unaided eye condition produced the least ($F = 9.72$, $df = 3/16$, $p<.01$).

Cyclic left-right absolute control movement magnitudes are shown in Figure 4 with the 60° and 40°b goggles sets having the largest magnitude of movements and the 40° and unaided eye conditions the least ($F = 5.34$, $df = 3/16$, $p<.01$). Figure 5 indicates that the unaided eye condition exhibited the longest mean times in control steady state cyclic left-right while the 40°b condition produced the shortest steady state times ($F = 4.15$, $df = 3/16$, $p<.05$). Higher cyclic left-right control movement mean times (Figure 6) were exhibited by the 40° and 40°b sets relative to the 60° goggles and the unaided eye conditions ($F = 5.88$, $df = 3/16$, $p<.01$).

2. Low Level Flight

Figures 7 through 9 show the means for the three performance measures which exhibited significant ($p<.05$) univariate F ratios for the low level flight segment. Figure 7 illustrates the higher airspeed exhibited by the unaided eye condition relative to the 40° and 40°b conditions ($F = 4.29$, $df = 3/16$, $p<.05$).

During low level flight, the 40° and 40°b goggle conditions (Figure 8) exhibited longer periods of time in cyclic left-right control steady state relative to 60° goggle and unaided eye conditions

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*Figures for the univariate data section are located in Appendix A.

(F = 3.27, df = 3/16, p<.05). It should also be noted that the 40° goggle condition showed (Figure 9) a larger standard deviation in heading than the three other visual sets (F = 5.01, df = 3/16, p<.05).

3. 360° Left Pedal Turn

Figures 10 through 13 show the means for the four performance measures which exhibited significant (p<.05) univariate F ratios for the 360° left pedal turn maneuver. Figure 10 illustrates the difference found in mean pitch angle among the visual conditions during the 360° left pedal turn, with the unaided eye condition having the highest nose-up attitude (largest pitch angle) and the 60° goggle set the smallest pitch angle (F = 7.45, df = 3/20, p<.01).

Figures 11, 12, 13 depict radar altitude error scores (constant error, average absolute error, and root mean square error, respectively) with the 60° goggle condition having, in each case, the greatest amount of error followed by the 40° goggle condition, the 40°b goggle condition and the unaided eye group. Thus the univariate examinations of the deviations from the command altitude of three feet revealed that the 60° goggle group had the largest amount of altitude error and the unaided eye the least error in all three analyses.

4. Hover Forward Flight Maneuver

Figures 14 and 15 show the means for the two performance measures which exhibited significant (p<.05) univariate F ratios for the hover forward flight maneuver. Figure 14 illustrates the difference in the number of cyclic fore-aft control movements among the four visual sets during the hover forward maneuver, with the unaided eye and 40°b groups having the most control movements while the 40° and 60° goggle conditions had the least (F = 3.44, df = 3/20, p<.05). Figure 15 shows the differences in magnitude of pedal control movement among the visual sets; the unaided eye group had the shortest average distance in movement while the 60° goggle group had the largest magnitude of movement (F = 3.20, df = 3/20, p<.05).

5. 25-Foot Hover Flight Maneuver

Figures 16 through 19 show the means for the two performance measures which exhibited significant (p<.05) univariate F ratios for the 25-foot hover flight maneuver. Figure 16 illustrates the differences in mean pitch angle for the four visual sets during the 25-foot hover, with the unaided eye condition having the largest pitch angle (highest nose-up attitude) and the 60° goggle group the smallest (F = 3.67, df = 3/20, p<.05). Figure 17 shows the number

of control movements with the cyclic in the left-right direction, with the 40°b group having the greatest number and the unaided eye group the least ($F = 4.97$, $df = 3/20$, $p<.01$).

Figure 18 indicates the magnitude of absolute average error along the x axis exhibited by the four groups. One can see that the greatest amount of absolute error was associated with the unaided eye group and the least with the 40°b condition ($F = 4.93$, $df = 3/20$, $p<.05$). RMS error along the x axis (Figure 19) also was found to be the greatest for the unaided eye condition and the least for the 40° goggle group ($F = 4.53$, $df = 3/20$, $p<.05$).

6. Hover Rearward Flight Maneuver

Figures 20 through 22 show the means for the four performance measures which exhibited significant ($p<.05$) univariate F ratios for the hover rearward flight maneuver. Figure 20 illustrates the difference in mean pitch angle among the four visual sets, with the unaided eye group having a higher nose-up attitude (greater pitch angle) than the three goggle groups ($F = 3.51$, $df = 3/20$, $p<.05$).

Figure 21 shows the difference in the number of left-right control movements made with the cyclic under the four visual sets; one can see that the 60° goggle group had the greatest number of control movements while the 40° goggle set had the least ($F = 4.58$, $df = 3/20$, $p<.05$). Figure 21 illustrates the difference in the mean number of pedal control movements made under the visual conditions, with the 60° and 40°b goggle sets having the most pedal control movements and the unaided eye and 40° goggles having the least.

Figure 22 lists the radar altitude constant error means for the four visual sets; the 60° goggle condition had the highest positive value while the 40° goggle group had the only negative constant error score.

B. Multivariate Data

1. NOE Flight

Table 7 indicates the five most discriminating performance measures in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F values and U-Statistic values. Table 8 indicates the resultant classification of aviators by the five performance variables in their respective groups. With the prior probability of group membership being equal, the performance scores for the NOE flight correctly classified 95% of the aviators into the appropriate visual set.

Table 7

Stepwise Discriminant Anaylsis - NOE Flight Summary Data

Variable Entered	F Value	df	P	U Statistic
Cyclic Left-Right Control Movement Number	9.72	3/16	< .01	0.35
Cyclic Left-Right Absolute Control Movement Magnitude	1.66	3/15	> .05	0.26
Mean Airspeed	1.72	3/14	> .05	0.19
Cyclic Fore-Aft Absolute Control Movement Magnitude	5.55	3/13	< .05	0.08
Cyclic Left-Right Control Movement Mean Time	6.54	3/12	< .01	0.03

Table 8

Number of Cases Classified into the Four Visual Sets Using the NOE Flight Data

	Visual Sets			
Groups	40°	60°	40°b	Unaided Eye
0°	5	0	0	0
60°	0	4	1	0
40°b	0	0	5	0
Unaided Eye	0	0	0	5

Summary data for the multiple discriminate analysis are shown in Table 9. Four of the six performance measures with significant univariate F ratio values were selected by the stepwise discriminant analysis and appear in Table 9. Of these four, only airspeed was a primary contributor to root 1 (which accounted for 74.1% of the variance, $X^2 = 32.3$, df = 7, $p < .0001$).

Table 9

Multiple Discriminant Analysis - NOE Flight Summary Data

Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F^a	Adjusted D Weights Root 1	Root II
Mean Airspeed[1]	26.55	27.48	27.20	29.83	4.33*	-0.106[b]	0.005
Cyclic Fore-Aft Absolute Control Movement Magnitude[2]	.62	.66	.65	.64	1.28	0.080[b]	-0.025[b]
Cyclic Left-Right Absolute Control Movement Magnitude[2]	.63	.63	.64	.59	5.34**	0.013	-0.003
Cyclic Left-Right Control Movement Number[3]	391.8	350.4	348.4	173.8	9.[illegible]**	0.031	-0.010
Cyclic Left-Right Control Movement Mean Time[4]	.16	.15	.16	.15	5.88**	0.020	0.023[b]

Root I - 74.1% of Variance, $X^2 = 32.3$, df = 7, $p < .0001$
Root II - 24.0% of Variance, $X^2 = 18.4$, df = 5, $p < .003$
Total Discriminatory Power (Estimated Omega Squared) = 0.96

[a] Univariate F, df = 3/16
[b] Primary contributor
* $p < .05$
** $p < .01$

Units of Measurement
1. Knots
2. Inches
3. Total Number
4. Seconds

Examination of Figure 23 indicates that the performance scores produced the greatest separation in root 1 between the unaided eye condition and the three goggle conditions. The total discriminatory power (Table 9) provided by the performance scores was found to be 0.96, or 96% of the variability was relevant to group differentiation. Stated differently, this 96% can be thought of as the total discriminatory power of the predictor battery as a whole.

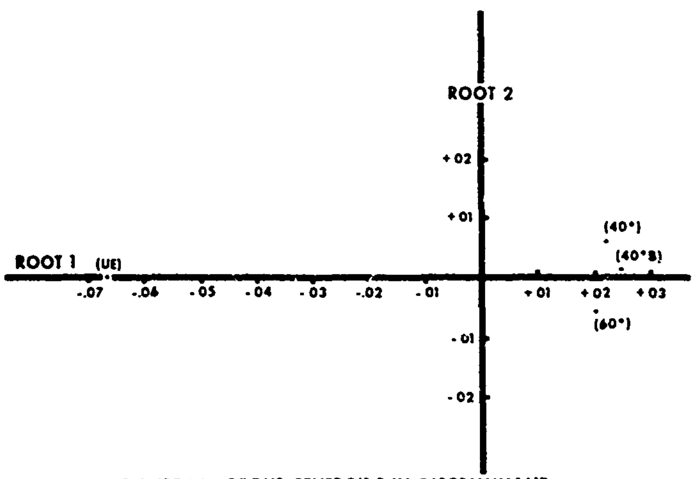


FIGURE 23 GROUP CENTROIDS IN DISCRIMINANT SPACE FOR THE NOE FLIGHT DATA

Inspection of the weights of the performance variables in root 1 (Table 9) indicates that root 1 was primarily defined by the variables mean airspeed (in a negative direction) and cyclic fore-aft absolute control movement magnitude (positive direction). The biggest discriminator in root 1 (Table 9) was mean airspeed and the negative sign associated with this weight indicates that slower airspeeds were associated with the three goggle conditions. Greater magnitude of cyclic fore-aft movements were also associated with the three goggle configurations.

The altitude at which the NOE course was flown by the aviators under each visual set was a critical factor. The mean radar altitude for the unaided eye group was approximately 62 feet, while the 40°, 40°b and 60° goggle conditions exhibited mean radar altitudes of 51 feet, 52 feet and 54 feet, respectively. Although these altitudes were not statistically different ($p > .05$) the similarity in goggle altitudes exhibited and the 8-11 foot higher mean altitude flown during the unaided eye condition was considered notable. Because the unaided eye group flew slightly higher through the river NOE course, fewer terrain obstacles were encountered, thus requiring fewer cyclic left-right control movements and smaller magnitude cyclic fore-aft control movements. Therefore a slightly higher altitude produced fewer terrain avoidance control movements resulting in a faster mean airspeed for the unaided eye condition relative to the three goggle conditions.

It should be noted again that the height of the trees along the river NOE course ranged from 75-95 feet. The flight data indicate that all four visual sets were effectively masked throughout most of the NOE flight. However, if tactical considerations demanded low altitude NOE flight, the goggles seemed to have provided a slightly lower altitude flight capability. The tradeoff for this lower altitude was: (1) a greater workload due to obstacle avoidance and (2) slower mean airspeeds.

Root 2 in the NOE flight analysis (Table 9) also accounted for a significant percentage of the variance - 24.0%, $X^2 = 18.4$, df = 5, $p < .003$. One can see in Figure 23 (NOE centroids) that root 2 produced the greatest separation between the 40° and 60° goggle conditions. Root 2 is primarily defined by the variables cyclic fore-aft absolute control movement magnitude (negative direction) and cyclic left-right control movement mean time (positive direction). The 40° goggle condition reflected smaller fore-aft cyclic movements and longer duration cyclic left-right movements relative to the 60° goggle condition. These two variables indicate that aviator performance with the 40° goggles exhibited smoother, more gradual control movements than with the 60° goggles. This finding seems to reflect the resolution difference between the two sets of goggles.

Perhaps the most important point to be made about the results of the NOE multivariate analyses is that the flight performance exhibited by the pilots under the unaided eye condition was distinctly different from that occurring under the goggle condition. That is, the three goggles' flight performances were, in toto, similar to each other and distinctly separated from the unaided eye group's performance (Figure 23). The classification matrix (Table 8) also supports this, in that, there was no statistical misclassification between the unaided eye group and the three goggle conditions.

2. Low Level Flight

Table 10 lists the five most discriminating performance measures in the low level flight analysis in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F values and U-Statistic values. Table 11 indicates the resultant classification of aviators into their respective groups by the five performance measures. With the prior probability of group membership being equal, the performance scores correctly classified 85% of the aviators into the appropriate visual condition.

Table 10

Stepwise Discriminant Analysis - Low Level Flight Summary Data

Variable Entered	F Value	df	P	U Statistic
Standard Deviation Heading	5.01	3/16	< .05	0.51
Collective Control Position Mean	3.47	3/15	< .05	0.30
Cyclic Left-Right Control Position Mean	8.87	3/14	< .01	0.10
Radar Altitude Mean	3.78	3/13	< .05	0.06
Mean Airspeed	3.31	3/12	> .05	0.03

Table 11

Number of Cases Classified into the Four Visual Sets
Using the Low Level Flight Data

	Visual Sets			
	40°	60°	40°b	Unaided Eye
Groups				
40°	5	0	0	0
60°	0	4	0	1
40°b	0	1	4	0
Unaided Eye	0	1	0	4

Summary data for the multiple discriminant analysis of the low level flight are shown in Table 12. Two of the three performance measures with significant univariate F ratios ($p<.05$) were utilized in the multiple discriminant analysis (Table 12). The variable standard deviation-heading was also a primary contributor to the first discriminant root.

Table 12

Multiple Discriminant Analysis - Low Level Flight Summary Data

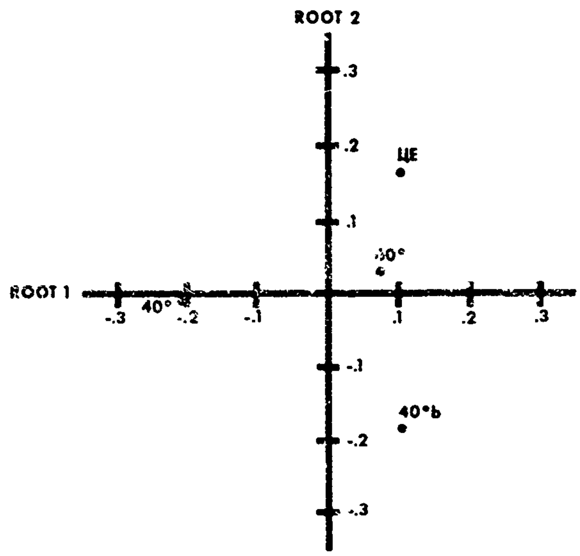
Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F[a]	Adjusted D Weights Root I	Root II
Mean Radar Altitude[1]	86.9	97.8	86.3	97.2	0.65	-0.283	0.425[b]
Mean Airspeed[2]	55.2	59.1	55.3	65.1	4.29*	0.022	0.378[b]
Standard Deviation-Heading[3]	3.98	2.55	2.85	2.65	5.01*	-0.809[b]	0.145
Cyclic Left-Right Control Position Mean[4]	-.66	-.58	-.34	-.63	1.36	0.417[b]	-0.208
Collective Control Position Mean[4]	3.52	3.47	3.43	3.49	0.28	0.396[b]	0.464[b]

Root I - 83.0% of Variance, $X^2 = 36.4$, df = 7, $p < .00001$
Root II - 16.0% of Variance, $X^2 = 16.1$, df = 5, $p < .007$
Total Discriminatory Power (Estimated Omega Squared) = 0.96

[a] Univariate F, df = 3/16
[b] Primary contributor
* $p < .05$
** $p < .01$

Units of Measurement
1. Feet
2. Knots
3. Degrees
4. Inches

Table 12 also indicates that root 1 accounted for a significant percentage of the variance--83.0%, $X^2 = 36.4$, df = 7, $p<.00001$. Examination of the centroids in Figure 24 indicates that the performance scores produced the greatest amount of separation between the 40° goggle condition and the three other visual sets. On root 2 the greatest amount of separation occurred between the unaided eye and 40°b visual conditions. The total discriminatory power (Table 12) provided by the performance scores was found to be 0.96, or 96% of the variability was relevant to group differentiation.



GROUP CENTROIDS IN DISCRIMINANT
SPACE FOR THE LOW LEVEL FLIGHT DATA
FIGURE 24

The weights of the performance measures in Table 12 indicate that root 1 was primarily defined by standard deviation-heading (negative direction), cyclic left-right control position mean (positive direction), and collective control position mean (positive direction). Therefore, groups with higher centroid values on root 1 (i.e., the unaided eye visual condition and 60° and 40°b goggle conditions) have, in general, smaller standard deviations in heading, larger (-) position mean values for the cyclic indicating more left cyclic input, and larger collective control position mean values. Of the three, the standard deviation-heading variable is the most informative in that it indicates that the 40° goggle condition had greater variability in heading relative to the other three visual conditions while flying the low level flight segment.

It should be noted that the unaided eye group flew faster than the other three visual conditions, in particular the 40° and 40°b goggle conditions. However, it should also be pointed out that this group was associated with a higher mean altitude relative to the 40° and 40°b goggle. Thus, the situation is somewhat similar to that found in NOE flight with regard to these parameters where the unaided eye condition was found to be associated with faster flight but likewise with higher flight. Therefore, with respect to the operational impact for the unaided versus the 40° goggle there would appear, based on these data, some need for consideration of the relative merits of speed versus altitude.

3. <u>360° Left Pedal Turn</u>

Table 13 lists the six most discriminating performance measures in the 360° left pedal turn analysis in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F values and U-Statistics values. Table 14 indicates the resultant classification of aviators into their respective groups by the six performance variables. With the prior probability of group membership being equal, the performance scores correctly classified 100% of the aviators into the appropriate visual set.

Table 13

Stepwise Discriminant Analysis - 360° Left Turn at a 3 Foot Hover

Variable Entered	F Value	df	P	U Statistic
Mean Pitch Angle	7.45	3/20	< .01	0.47
Radar Altitude RMS	11.99	3/19	< .01	0.16
Cyclic Fore-Aft Absolute Control Movement Magnitude	5.42	3/18	< .01	0.08
Cyclic Left-Right Control Movement Number	5.83	3/17	< .01	0.04
Pedal Control Movement Number	5.36	3/16	< .01	0.02
Constant Error in X	4.66	3/15	< .05	0.01

Table 14

Number of Cases Classified into the Four Visual Sets Using the 360° Left Turn at a 3 Foot Hover Data

	Visual Sets			
	40°	60°	40°b	Unaided Eye
Groups				
40°	6	0	0	0
60°	0	6	0	0
40°b	0	0	6	0
Unaided Eye	0	0	0	6

Summary data for the multiple discriminant analysis of the 360° left pedal turn are shown in Table 15. Two of the four performance measures with significant univariate F ratios were utilized, in this case, in the multiple discriminant analysis (Table 15). However, only the variable mean pitch angle was a primary contributor to the first discriminant root.

Table 15

Multiple Discriminant Analysis - 360° Left Turn at Hover Summary Data

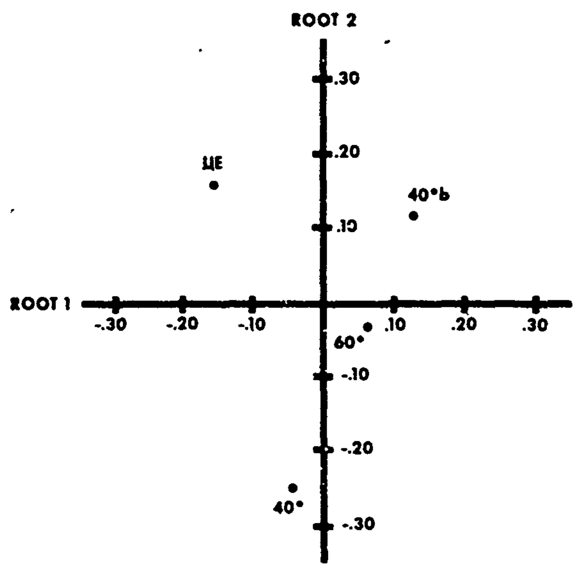
Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F^a	Adjusted D Weights Root I	Adjusted D Weights Root II
Mean Pitch Angle[1]	2.72	2.19	2.71	3.68	7.45**	-0.26^b	0.61^b
Cyclic Fore-Aft Absolute Control Movement Magnitude[2]	.67	.67	.65	.73	1.44	-0.28^b	-0.27
Cyclic Left-Right Control Movement Number[3]	15.2	17.7	22.3	19.0	2.65	0.47^b	-0.07
Pedal Control Movement Number[3]	4.5	6.2	6.3	7.8	1.46	-0.25^b	0.14
Constant Error Along the X Axis[4]	-11.83	-12.85	-11.85	-9.2	0.29	-0.16	0.09
Radar Altitude RMS[4]	6.33	10.31	3.75	3.27	5.82**	-0.08	-0.73^b

Root I - 83.1% of Variance, $X^2 = 54.6$, df = 8, $p < .0001$
Root II - 15.8% of Variance, $X^2 = 27.2$, df = 6, $p < .0003$
Total Discriminatory Power (Estimated Omega Squared) = 0.99

[a] Univariate F, df = 3/20
[b] Primary contributor
** $p < .01$

Units of Measurement
1. Degrees
2. Inches
3. Total Number
4. Feet

Table 15 also indicates that root 1 accounted for a significant portion of the variance--83.1% (X^2 = 54.6, df = 6, p<.0001); root 2 also accounted for a significant portion of the variance--15.8% (X^2 = 27.2, df = 6, p<.0003). Examination of the group centroids in Figure 25 indicates that the performance scores produced the greatest separation in root 1 between the unaided eye and 40°b conditions. The greatest amount of separation in root 2 was between the unaided eye and 40° goggle conditions. The total discriminatory power (Table 15) provided by the performance scores was found to be 0.99, or 99% of variability was relevant to group differentiation.



GROUP CENTROIDS IN DISCRIMINANT SPACE FOR THE 360° LEFT PEDAL TURN DATA
FIGURE 25

Inspection of the weights of the performance variables in root 1 (Table 15) indicates that root 1 is primarily defined by the variable cyclic left-right control movement number (positive direction) and to a lesser extent by cyclic fore-aft absolute control movement magnitude (negative direction), mean pitch angle (negative direction), and pedal control movement number (negative direction). Therefore, groups with higher centroid values on root 1 (i.e., 40°b and 60° goggle visual sets) have, in general, a larger number of cyclic left-right control movements, smaller control movements with the cyclic in the fore-aft direction, smaller mean pitch angles and a smaller number of pedal control movements.

A secondary contributor to the first discriminant root, constant error along the X axis, indicates that negative constant error scores

were exhibited by all visual conditions. However, less negative constant error or drift was associated with the unaided eye condition indicating that this group detected the drift sooner than the three goggle conditions. It appears that the aviators were more accustomed to hovering at very low altitudes with the unaided eye and thus were able to obtain the necessary visual information for maintaining the aircraft near the initial hover coordinates.

4. Hover Forward Flight Maneuver

Table 16 lists the six most discriminating performance measures in the hover forward flight analysis in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F values and U-Statistic values. Table 17 indicates

Table 16

Stepwise Discriminant Analysis - Hover Forward Flight Summary Data

Variable Entered	F Value	df	P	U Statistic
Cyclic Fore-Aft Control Movement Number	3.44	3/20	$< .05$	0.66
Cyclic Left-Right Control Movement Number	7.33	3/19	$< .01$	0.31
Mean Airspeed	4.44	3/18	$< .05$	0.18
Collective Control Steady State Mean Time	4.92	3/17	$< .05$	0.09
Mean Radar Altitude	5.60	3/16	$< .01$	0.05
Pedal Control Movement Number	2.95	3/15	$> .05$	0.03

Table 17

Number of Cases Classified into the Four Visual Sets Using the Hover Forward Flight Data

	Visual Sets			
	40°	60°	40°b	Unaided Eye
Groups				
40°	5	1	0	0
60°	1	5	0	0
40°b	1	0	5	0
Unaided Eye	0	0	0	6

the resultant classification of aviators into their respective groups by the six performance variables. With the prior probability of group membership being equal, the performance scores correctly classified 80% of the aviators into the appropriate visual condition.

Summary data for the multiple discriminant analysis of the hover forward flight data are shown in Table 18. One of the two performance measures with significant univariate F ratios was utilized, in this case, in the multiple discriminant analysis (Table 18). This variable, cyclic fore-aft control movement number, was also a primary contributor to the first discriminant root.

Table 18

Multiple Discriminant Analysis - Hover Forward Flight Summary Data

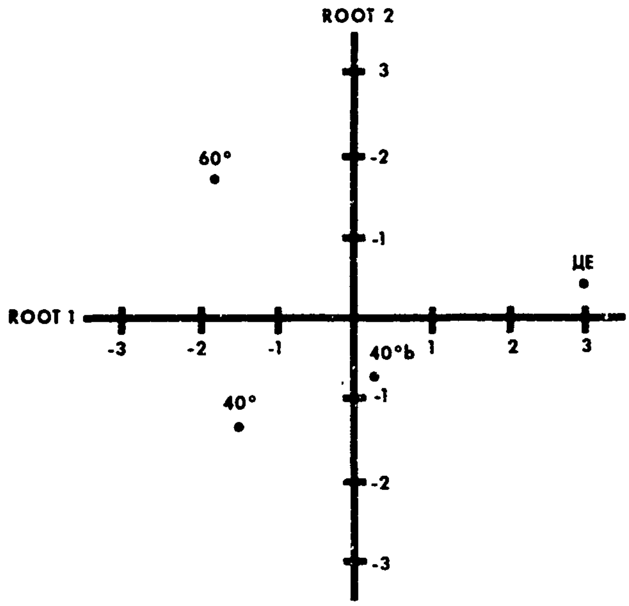
Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F^a	Adjusted D Weights Root I	Root II
Mean Radar Altitude[1]	3.79	6.96	3.64	3.51	1.72	3.19	7.85[b]
Mean Airspeed[2]	11.09	10.95	9.91	9.[illegible]3	1.77	- 6.00	-4.67[b]
Cyclic Fore-Aft Control Movement Number[3]	21.5	21.7	24.3	27.[illegible]	3.44*	16.06[b]	-1.26
Cyclic Left-Right Control Movement Number[3]	12.8	12.8	14.0	18.3	0.26	-10.80[b]	-4.09[b]
Collective Control Steady State Mean Time[4]	20.45	36.34	22.49	40 69	2.73	- 3.91	-0.49
Pedal Control Movement Number[3]	2.67	5.33	2.83	6.33	2.09	- 1.59	6.50[b]

Root I - 91.3% of Variance, X^2 = 50.7, df = 8, p < .0001
Root II - 8.0% of Variance, X^2 = 14.78, df = 6, p < .022
Total Discriminatory Power (Estimated Omega Squared) = 0.96

[a] Univariate F, df = 3/20
[b] Primary contributor
* p < .05

Units of Measurement
1. Feet
2. Knots
3. Total Number
4. Seconds

Table 18 also indicates that root 1 accounted for a significant percentage of the variance--91.3%, $X^2 = 50.7$, df = 8, p<.0001; root 2 also accounted for a significant percentage of the variance--8.0%, $X^2 = 14.7$, df = 6, p<.022. Examination of the group centroids in Figure 26 indicates that the performance scores produced the greatest amount of separation in root 1 between the 60° goggle condition and the unaided eye group. On root 2, the greatest amount of separation occurred between the 40° and 60° goggle conditions. The total discriminating power (Table 18) provided by the performance scores was found to be 0.96, or 96% of the variability was relevant to group differentiation.



GROUP CENTROIDS IN DISCRIMINANT
SPACE FOR THE HOVER FORWARD FLIGHT MANEUVER
FIGURE 26

Examination of Figure 26 shows that on root 1 the goggles were more similar than different relative to the unaided eye. All visual conditions yielded similar system performance with regard to airspeed and altitude except for 60° goggles. This visual set was associated with a higher altitude, a result which has been noted earlier and one which might possibly be related to their resolving power. With respect to the cyclic and pedal control inputs, the unaided eye condition was associated with more control activity. It can be seen as a function of the separation on root 1 the positive sign on the cyclic, because of the mean difference and weight size, had the greater impact. It must also be remembered that the coefficients are weighted and signed to provide maximum discrimination between all groups. Therefore, for this maneuver the system output performance with the exception of the 60° condition were nearly equal while the unaided eye condition relative to the goggles was associated with more cyclic and pedal activity.

5. <u>Twenty-five Foot Hover Flight Maneuver</u>.

Table 19 lists the six most discriminating performance measures in the 25-foot hover flight analysis in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F values and U-Statistic values. Table 20 indicates

the resultant classification of aviators into their respective groups by the six performance measures. With the prior probability of group membership being equal, the performance scores correctly classified 92% of the aviators into the appropriate visual condition.

Table 19

Stepwise Discriminant Analysis - 25 Foot Hover Summary Data

Variable Entered	F Value	df	P	U Statistic
Cyclic Left-Right Control Movement Number	4.97	3/20	< .01	0.57
X Axis Average Absolute Error	3.18	3/19	< .05	0.38
Mean Pitch Angle	3.61	3/18	< .05	0.23
Cyclic Fore-Aft Control Movement Number	2.96	3/17	> .05	0.15
Pedal Control Steady State Mean Time	4.31	3/16	< .05	0.09
Collective Control Steady State Mean Time	2.32	3/15	> .05	0.06

Table 20

Number of Cases Classified into the Four Visual Sets
Using the 25 Foot Hover Data

	Visual Sets			
Groups	40°	60°	40°b	Unaided Eye
40°	6	0	0	0
60°	0	6	0	0
40°b	0	0	5	1
Unaided Eye	0	1	0	5

Summary data for the multiple discriminant analysis of the 25-foot hover data are shown in Table 21. Three of the four performance measures with significant univariate F ratios ($p<.05$) were utilized in the multiple discriminant analysis (Table 21). All three of these variables, mean pitch angle, cyclic left-right control movement number and X axis average absolute error, were also primary contributors to the first discriminant root.

Table 21

Multiple Discriminant Analysis - 25 Foot Hover Summary Data

Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F^a	Adjusted D Weights Root I	Adjusted D Weights Root II
Mean Pitch Angle[1]	4.49	4.26	4.47	4.94	3.67*	-1.65[b]	-1.64
Cyclic Fore-Aft Control Movement Number[2]	33.3	33.3	32.8	26.0	0.98	2.13[b]	0.24
Cyclic Left-Right Control Movement Number[2]	6.8	12.7	21.0	6.5	4.97**	-1.13[b]	4.04[b]
Collective Control Steady State Mean Time[3]	42.0	57.0	44.2	48.8	1.42	-0.79	2.41[b]
Pedal Control Steady State Mean Time[3]	26.6	20.3	15.8	12.5	1.39	1.53[b]	-0.35
X Axis Average Absolute Error[4]	9.94	11.44	7.53	15.67	4.93**	-1.69[b]	-0.02

Root I - 67.1% of Variance, $X^2 = 29.7$, df = 8, $p < .0005$
Root II - 23.5% of Variance, $X^2 = 16.0$, df = 6, $p < .014$
Total Discriminatory Power (Estimated Omega Squared) = 0.92

[a] Univariate F, df = 3/16
[b] Primary Contributor
* $p < .05$
** $p < .01$

Units of Measurement
1. Degrees
2. Total Number
3. Seconds
4. Feet

Table 21 also indicates that root 1 accounted for a significant percentage of the variance - 67.1%, $X^2 = 29.7$, df = 8, $p<.0005$. Examination of the group centroids in Figure 27 indicates that the performance scores produced the greatest amount of separation on root 1 between the 40°b and 60° goggles conditions. On root 2 the greatest amount of separation occurred between the 40°b and unaided eye conditions. The total discriminatory power (Table 21) provided by the performance scores was found to be 0.92, or 92% of the variability was relevant to group differentiation.

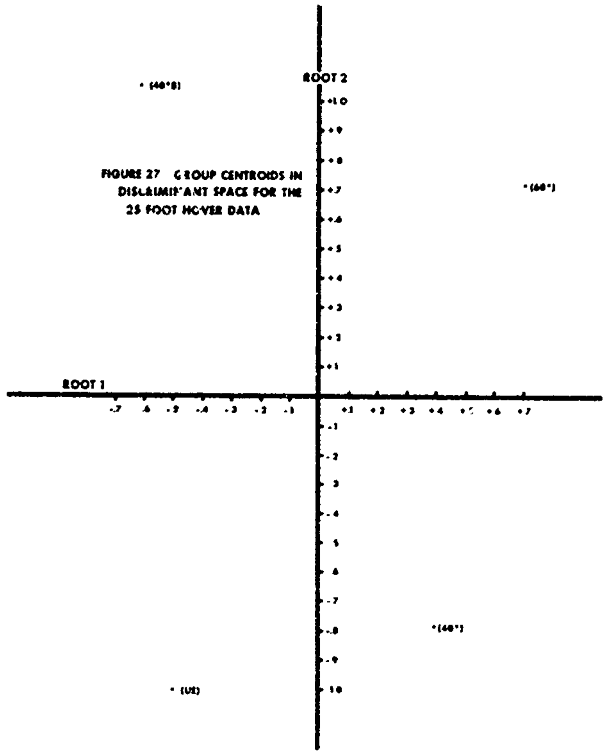


FIGURE 27 GROUP CENTROIDS IN DISCRIMINANT SPACE FOR THE 25 FOOT HOVER DATA

The weights of the performance measures in Table 21 indicate that root 1 was primarily defined by cyclic fore-aft control movement number (positive direction) and to a lesser extent by X axis average absolute error (negative direction), mean pitch angle (negative direction), pedal control steady state mean time (positive direction) and cyclic left-right control movement number (negative direction). Therefore, groups with higher centroid values on root 1 (i.e., 60° and 40° goggle groups) have, in general, more control movements with the cyclic in the fore-aft direction, smaller average absolute error in X, smaller mean pitch angle (a more nose-down attitude relative to the other two groups), a greater amount of time in pedal control steady state and fewer control movements with the cyclic in the left-right direction.

Individually, the average absolute error on the X axis (horizontal displacement) prevails as the dominant performance measure of the 25-foot hover maneuver. This variable was not only significant univariately but also was a primary contributor to the first discriminant root. The means for this variable indicate that the aviators flying with the 40°b and 40° goggle configurations were better able to maintain their position over the starting point relative to the unaided eye and the 60° goggle condition. Also, performance with the three goggle conditions reflected superior drift control compared to the unaided eye. The ordering of means along this error variable follows what seems to be a visual resolution continuum with the 40°b and

40° goggles having the highest resolution and the least error, followed by the 60° goggles and the unaided eye which degraded resolution and correspondingly higher error values. When combined with other performance measures on the 25-foot hover data, this resolution/horizontal drift continuum was lost. The 40°b goggle and 40° goggle centroids, which had the least horizontal error, were separated in discriminant space through the influence of, primarily, the cyclic left-right control movement number parameter. On most of the other flight parameters, the 40°b goggle and 40° goggle conditions exhibited similar mean values; however, the 40°b goggle condition exhibited more cyclic left-right control movements than the other conditions. This higher number of cyclic left-right movements seems to be a function of the highly reduced outside field-of-view associated with the 40°b. The field-of-view available for outside use was limited to the upper 70% of the lenses on the 40°b. Thus the aviators were forced to scan left and right more to obtain the visual information needed to maintain the high hover, which seems to have also produced the higher number of cyclic left-right movements. However, this scan pattern and/or cyclic left-right activity appears to have resulted in a very low error in the horizontal direction for the 40°b group. The variable X axis average absolute error was not highly correlated with the other variables utilized, so horizontal drift could not be predicted from the other performance measures of concern in the 25-foot hover analysis.

Root 2 of the 25-foot hover also accounted for a significant percentage of the variance--23.5%, $X^2 = 16.0$, df = 6, $p<.014$. The two primary contributors on this root indicated that the two groups with high centroid values (40°b and 60°) had more cyclic left-right control movements and longer periods of control steady state times between collective control movements relative to the unaided eye and 40° goggle conditions.

6. Hover Rearward Flight Maneuver.

Table 22 lists the six most discriminating performance measures in the hover rearward flight analysis in the order they were selected by the stepwise discriminant analysis along with their associated multivariate F and U-Statistic values. Table 23 indicates the resultant classification of aviators into their respective groups by the six performance variables. With the prior probability of group membership being equal, the performance scores were used to correctly classify 100% of the aviators into the appropriate visual condition.

Table 22

Stepwise Discriminant Analysis - Hover Rearward Flight Summary Data

Variable Entered	F Value	df	P	U Statistic
Pedal Control Movement Number	12.45	3/20	< .01	0.35
Radar Altitude Constant Error	3.22	3/19	< .05	0.23
Radar Altitude Average Absolute Error	4.31	3/18	< .05	0.13
Pedal Control Movement Mean Time	5.20	3/17	< .01	0.07
Cyclic Fore-Aft Control Movement Number	4.28	3/16	< .05	0.04
Cyclic Fore-Aft Control Movement Magnitude	2.69	3/15	> .05	0.02

Table 23

Number of Cases Classified into the Four Visual Sets
Using the Hover Rearward Flight Data

	Visual Sets			
	40°	60°	40°b	Unaided Eye
Groups				
40°	6	0	0	0
60°	0	6	0	0
40°b	0	0	6	0
Unaided Eye	0	0	0	6

Summary data for the multiple discriminant analysis of the hover rearward flight data are shown in Table 24. Two of the four performance measures with significant univariate F ratios were utilized in this case, in the multiple discriminant analysis (Table 24). These two variables, pedal control movement number and radar altitude constant error, were also primary contributors to the first discriminant root.

Table 24 also indicates that root 1 accounted for a significant percentage of the variance - 68.7%, $X^2 = 22.1$, df = 6, $p<.002$. Examination of the group centroids in Figure 28 indicates that the performance scores produced the greatest amount of separation in root 1 between the unaided eye condition and the 60° goggle group. On root 2, the greatest amount of separation occurred between the 60° and 40° goggle conditions. The total discriminatory power (Table 24) provided by the performance measures was found to be 0.97, or 97% of the variability was relevant to group differentiation.

Inspection of the weights of the performance measures in Table 24 indicates that root 1 was primarily defined by the variable radar altitude constant error (positive direction) and to a lesser extent by radar altitude absolute average error (negative direction), pedal control movement number (positive direction) and pedal control movement mean time (negative direction). Therefore, groups with higher centroid values on root 1 (i.e., 60° and 40° goggles) have, in general, greater constant error in altitude values, less absolute average error in altitude, more pedal control movements, and shorter mean time in pedal control movements. A strict interpretation of the first discriminant function (that is, using the weights and signs of the weights as the guide points) indicates that for the 60° and 40° goggle conditions, aviators (1) hovered rearward at higher mean altitudes with less total absolute error in altitude from the five foot command altitude than the 40°b and unaided eye groups, and (2) made more and quicker pedal control movements (compared to the 40°b and unaided eye groups).

A slightly different view of the flight performance of the four groups is provided if the two radar altitude error scores are examined without regard to the control measures. The 40° and 40°b goggle conditions hovered rearward at lower mean altitudes thus they were closer to the command altitude of five feet AGL than the 60° goggle and unaided eye conditions. The 40° and 40°b conditions also exhibited slightly less total absolute error from the command altitude than did the 60° goggle and unaided eye conditions.

Root 2 on the hover rearward data also accounted for a significant percentage of the variance - 23.8%, $X^2 = 22.1$, df = 6, $p<.0002$. The largest separation was between the 60° and 40° goggle conditions with three variables primarily contributing to this separation. The weights for these variables indicate that 60° and 40°b goggles had the largest magnitude of cyclic fore-aft absolute control movement and the largest number of cyclic fore-aft control movements as well as the longest average time for pedal control movements, relative to the unaided eye and the 40° goggle conditions.

The 100% classification strongly illustrates the difference in aviator performance during the hover rearward maneuver under the four

Table 24

Multiple Discriminant Analysis - Hover Rearward Flight Summary Data

Variable	40° Mean	60° Mean	40°b Mean	Unaided Eye Mean	F[a]	Adjusted D Weights Root I	Root II
Cyclic Fore-Aft Absolute Control Movement Magnitude[1]	0.65	0.68	0.75	0.66	2.62	-0.025	0.227[b]
Cyclic Fore-Aft Control Movement Number[2]	20.8	34.8	33.3	27.5	2.13	-0.279	0.435[b]
Pedal Control Movement Number[2]	3.8	9.3	6.0	3.8	12.46**	0.449[b]	0.201
Pedal Control Movement Mean Time[3]	0.17	0.25	0.27	0.26	1.70	-0.390[b]	0.256[b]
Radar Altitude Constant Error[4]	-0.27	4.17	1.97	2.27	3.38*	0.615[b]	-0.149
Radar Altitude Average Absolute Error[4]	2.99	5.54	3.56	5.95	1.58	-0.469[b]	-0.205

Root I - 68.7% of Variance, X^2 = 37.8, df = 8, p < .0001
Root II - 23.8% of Variance, X^2 = 22.1, df = 6, p < .002
Total Discriminatory Power (Estimated Omega Squared) = 0.97

a Univariate F, df = 3/20
b Primary contributor
* p < .05
** p < .01

Units of Measurement
1. Inches
2. Total Number
3. Seconds
4. Feet

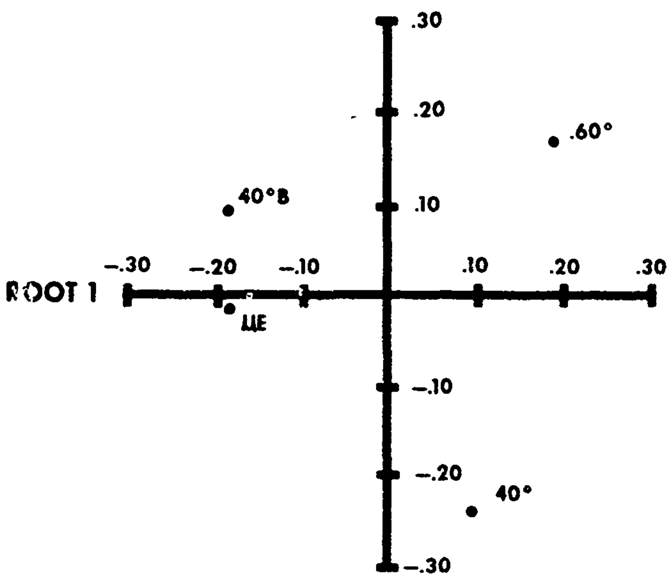


FIGURE 28

GROUPS CENTROIDS IN DISCRIMINANT SPACE FOR THE HOVER REARWARD DATA.

visual conditions. While the control movement variables helped to produce this magnitude of separation across the groups, the radar altitude variables were the primary discriminators.

C. Responses to the Night Vision Goggle Questionnaire

Following the in-flight performance measurement under the various visual sets, the aviators completed a questionnaire designed to obtain their opinion about the night vision goggles. The information about the NVG's was divided into five general categories: (1) comparison of the two NVG fields-of-view, (2) flight maneuvers, (3) psychophysiological effects, (4) equipment consideration, and (5) academic and flight training. The following information represents a summary of the responses to items in the questionnaire.

1. Comparison of the Two NVG Fields-of-View

The aviators were asked if they could distinguish between the 40° and 60° FOV AN/PVS-5's and note the differences between the two pair of goggles. Five of the seven aviators rated the 40° goggles as the better of the two. Two of the aviators did not rate one pair over the other but listed the advantages and disadvantages of each pair. All seven aviators described the 40° goggles as having clearer resolution or a sharper image. Table 25 lists the advantages and disadvantages associated with both the 40° and 60° goggles. The 40° goggles were thought, by one individual, to be more physically

Table 25

Comparison of the 40° and 60° FOV NVG

40° Goggles	60° Goggles
Advantages	Advantages
1. Clearer resolution, sharper image	1. Larger field of vision
2. Physical comfort	2. Better depth perception
	3. More light
Disadvantages	Disadvantages
1. Smaller field of vision	1. Poorer resolution
2. Poorer depth perception	2. Cause of motion sickness
	3. Physical discomfort
	4. Goggles gave the impression of being dirty or out of focus

comfortable than the 60° goggles (Table 25). It seems that the mounting devices for the 60° goggles used in the current project did not maintain support for that set during the flight testing sessions. For one individual, at least, the 60° goggles' strap mounting system loosened after a few minutes of flight, allowing the goggles to slip slightly down on his face, resulting in less physical comfort.

2. Flight Maneuvers

The aviators were asked to evaluate the terrain features and light levels which would be necessary for them to maintain a 5-foot and 25-foot hover. Table 26 indicates the light levels desired by at least four of the seven aviators under three terrain conditions.

Table 26

Light Levels Necessary for Maintaining at 5 Foot and 25 Foot Hover with the NVG

		Illumination Levels					
Goggles	Terrain	No Moon, Overcast	No Moon, Starlight	0-1/8 Moon	1/8-1/4 Moon	1/4-1/2 Moon	1/2-Full Moon
40°	Smooth Open Field				X		
	Contoured Field				X		
	Large Opening in Trees			X			XX
60°	Smooth Open Field				X		
	Contoured Field				X		
	Large Opening in Trees			X			XX
40° Bifocals	Smooth Open Field						X
	Contoured Field				X		
	Large Opening in Trees				X		XX

X - Light level desired by the majority (4 of 7) of aviators for maintaining a five-foot hover.

XX - Light level desired by the majority (4 of 7) of aviators for maintaining a twenty-five foot hover.

There seemed to be a definite interaction between light levels and terrain in the aviators' attitude toward hovering. Using the 40° and 60° goggles, they felt that higher light levels were needed to perform a stable 5-foot hover over smooth open fields and contoured fields (1/8 - 1/4 moon) as compared to a large opening in the trees (0 - 1/8 moon). Higher light levels were thought to be required for hovering with the bifocals at 5-feet AGL over a smooth open field (1/2 - full moon) while only 1/8 - 1/4 moon was deemed necessary for maintaining a 5-foot hover over a contoured field and in a large opening in trees. The large opening in trees would provide texture gradients, contrast cues and other visual information for judging both horizontal and vertical movement, which would be lacking in the other two terrain conditions.

Hovering at 25-feet AGL was considered more difficult by the pilots because visual contact with references on the ground was limited. Therefore, the feeling was that light levels on the order of 1/2 to full moon were necessary for stable hovering at 25-feet AGL in a large opening in trees with the 40°, 60°, and bifocal goggles. The aviators were even more uncertain about hovering at 25-feet AGL with all three goggles over smooth and contoured fields because of the aforementioned dearth of visual information under those conditions.

Other factors which might influence hovering capabilities were listed as (1) points of reference outside the aircraft, (2) wind, (3) usable field-of-view, (4) depth perception and (5) cockpit visual environment (combination of goggles and structural parts restricting vision).

All seven aviators found that the goggles influenced their ability to judge both airspeed and altitude (primarily altitude). Some of the comments associated with these reduced capabilities were (1) inability to focus on an object close to the aircraft, (2) limited visual cues, (3) lack of peripheral information and (4) depth perception limited due to "tunnel vision" effect. Most aviators felt that improvement would occur with practice.

It seems that approximately the same light levels are required for all three pairs of goggles (40°, 60°, 40° bifocals) to perform the same flight maneuvers. However. the pilots did indicate that different light levels were required for different flight maneuvers, no matter what pair of goggles was used. In the following table (Table 27) a check (X) mark was placed in the block which reflected the average light level considered necessary for each type of flight.

The order of preference for the three pairs of goggles for enroute flight was (1) 40° bifocals, (2) 40°, and (3) 60°. The 40° bifocal goggles were preferred for enroute flight because they enabled the pilot to monitor the instrument panel with the lower portion of the split lense while also maintaining an outside capability with the top portion of the lense. However, the general attitude toward the altitude of flight which would be the most appropriate for each was that all three pairs were good for low altitude flight with the 40° and 60° goggles most appropriate for NOE or 0-50 feet AGL, while the bifocals, perhaps, would be more effective at 25-100 feet AGL. The bifocals were considered less desirable for NOE and Low Level flight because the lower portion of the lenses, focused for inside viewing, restricted even farther the critical field-of-view needed for terrain surveillance at low altitudes. The aviators expressed

Table 27

Light Levels Necessary for Different Flight Maneuvers

	Illumination Levels					
	No Moon	No Moon, Starlight	0-1/8 Moon	1/8-1/4 Moon	1/4-1/2 Moon	1/2-Full Moon
Enroute Flight		X				
NOE					X	
Low Level			X			
Contour				X		
Low Altitude (300-500 Ft AGL)			X			
Normal Take-Offs		X				
Normal Landings		X				
Max Performance Take-Offs	X					
Steep Landings			X			

that they were not able to hover as well with the 40° bifocal goggles as the 40° and 60° goggles due to difficulty in viewing ground features immediately below the aircraft. To view the ground through the top portion of the goggles, the aviators had to tilt their heads forward to an uncomfortable position.

Previous use indicated that basically two types of head movement techniques were used with the NVG's: (1) fixating on a point, and/or (2) constantly moving one's head from side to side. The side to side head movement technique was preferred in the dynamic flight maneuvers (e.g., NOE flight, normal and steep landings, and max performance takeoffs) in order to compensate for the limited field-of-view and thus obtain information needed for avoiding obstacles, making valid depth perception judgments and judging altitudes and rate of movement. More static flight maneuvers (e.g., 3-feet and 25-feet hovering) seemed to require some of the subjects to fixate on a point of reference. However, several aviators noted that both head movement techniques were utilized in all maneuvers.

The following safety suggestions were made for enhancing safe NVG aided flight: (1) orientation flights, (2) experienced safety pilots, (3) normal flight safety precautions, (4) filters for lights in the cockpit such as the master caution light, (5) low level cockpit illumination, (6) emergency light source, (7) adequate training and practice, and (8) easy removal of goggles.

In discussing the advantages and disadvantages of the NVG's in comparison to the unaided eye, the aviators noted the primary advantages as being (1) increased resolution and detail, (2) capabilities for NOE and low level flight under low light levels, and (3) greater distant vision capabilities. However, the disadvantages primarily concerned the question of whether or not the increased resolution was worth the sacrifice in peripheral vision. Other disadvantages listed were (1) reduced depth perception, (2) "whiteouts" due to bright lights, (3) more frequent exaggerated head movements, (4) fatigue, (5) inability to monitor instruments with 40° and 60° goggles (non-bifocal), (6) physical discomfort, and (7) inability to see detail at close range (non-bifocal).

When asked what visual condition (either unaided eye or one of the three pairs of goggles) they would choose if asked to fly the NOE course and the maneuvers again, the aviators indicated that the 40° goggles were the preferred visual set. One aviator preferred the 60° goggles for the NOE course because he felt that they provided better depth perception information than the other conditions. Another aviator chose the unaided eye for the NOE course because less head movement was required. Two individuals indicated that they would fly the NOE course again under any visual set except the 60° goggles.

3. Psychophysiological Effects

It was found that there were few negative psychophysiological effects associated with the use of the NVG's. Two aviators became nauseated while wearing the 60° NVG's, one due to the inability to focus the NVG's, the other while performing a 360° hover turn. Only one person experienced a headache while wearing the goggles while several mentioned facial discomfort due to the weight of the goggles on the cheek bones. Only one person experienced vertigo (due to quick head movements compensating for the small field-of-view) while none of the pilots ever felt particularly closed in (claustrophobia). However, most of the pilots indicated that they were more tense when wearing the PVS-5's as compared to the unaided eye conditions because of the: (1) tunnel vision or restricted field-of-view, (2) poor depth perception, and (3) unfamiliarity or lack of confidence in the goggles.

4. Equipment Considerations

Several of the pilots experienced difficulty with the helmet mounting of the goggles. The basic complaints were that: (1) the goggles fit too low on the face and (2) the mounting procedure was complicated or took too long.

Data from the study indicated that the primary design problem with PVS-5's was that the weight was not distributed equally across the helmet and helmet liner. The result was that most of the pressure or weight was on the face (cheeks and forehead) and the nape of the neck. Most of the pilots recommended that additional pressure relief pads be used on the cheeks. Some of the recommendations for improving the mounting of the goggles were (1) transfer the weight from the cheeks to the top of the helmet, (2) use supporting frame to keep the goggles from sliding forward, (3) mount the goggles permanently to the helmet visor and swing them down for use, (4) get a new frame for the lenses, and (5) keep the frame from touching the [illegible].

Due to the above conditions the pilots felt that if asked to go on an extended mission, the average length of time they could wear the goggles was 2.25 hours.

Structural problems associated with the use of the PVS-5's was the interference of vision by the center windscreen mount and the right forward door frame.

The majority of the aviators noted that outside lights such as car lights, spot lights, antenna lights, lights on other aircraft, and river reflections made vision difficult while using the goggles. They indicated that these light sources caused a "greenout", "flashout", or decreased resolution which lasted from 1-2 seconds to 10 seconds.

5. Academic and Flight Training*

The subjects were asked how much classroom or ground time they felt should be devoted to topics related to the NVG's. The following indicates the topics we suggested as well as topics they suggested that should be covered along with average times allocated to each:

Topics	Time Needed
Mounting	35 min
Focusing	50 min
Other adjustments	30 min
Background information on the NVG's and light levels	50 min

*It should be noted that the California Forest Service[16] has compiled a detailed flight training instruction program for aviators preparing to utilize the AN/PVS-5 NVG.

Tactical advantages	30 min
Safety inflight	30 min
Scanning procedures	12 min
Depth perception	120 min
Various types of flight environments	60 min
Additional light level information	25 min
Night blindness	15 min
Physiology of vision	60 min
Night flying	60 min

The topics which they considered as the more important areas to be covered were:

(1) Physiology of the eye
(2) Night vision
(3) Flying at various light levels
(4) Flying in various environments
(5) Proper adjustment, focusing, mounting
(6) Head movements
(7) Characteristics of the NVG
(8) Tactical usage

These are not ranked as to importance.

The aviators were almost in complete agreement in opinion that the Aviation School should provide all initial rotary wing students with NOE night vision goggle introduction and/or familiarization, but not bring all initial rotary wing students to full qualification with the NVG's. An average of 2.4 flight hours were considered essential for AN/PVS-5 student introduction.

In the opinion of aviators, an initial rotary wing student finishing his tactical training would need an average of 1.5 flight hours with the NVG's before he should take over the controls. The range was from immediately, or 0 to 4 hours flight training necessary.

Five of the seven aviators felt that a safety ride would be essential before they took over the controls for the first time. This safety ride would enable the pilots to get accustomed to the goggles and determine the limitations and capabilities of the goggles. The other two pilots felt that an aviator should be able to fly immediately if a safety pilot was ready at the controls.

Three of the pilots thought that when full qualification was given, the Aviation School should provide that service while three other

aviators felt that the Aviation School should provide only the AN/PVS-5 introduction while full qualification should be given as unit level training. The flight training averaged out as follows:

Introduction	Full Qualification	IP Qualification
2.4 hrs.	29.2 hrs. (Assumed IERW training complete)	52.1 hrs. (22.9 additional from full qualification)

Five aviators expressed that a special group of IP's assigned solely to night vision training would be more advantageous than having tactics or NOE IP's providing NVG training along with their other duties. The advantages of having special NVG IP's were listed as: (1) a great deal of familiarity and proficiency is needed with AN/PVS-5's for flight safety, (2) standardization is a must for training, (3) proficiency greatly increases with continued exposure, (4) vast amount of technique involved, and (5) night vision suffers from day work. The advantages listed for having the tactics or NOE IP's as the instructors for NVG's were (1) this approach is more realistic due to manpower considerations, and (2) students only need an introduction to the NVG's. The pilots indicated that large training programs with AN/PVS-5's may have some problems with such factors as weather, moon cycle, and moon rise and moon set. They also felt that a 2:1 student-instructor ratio for training would be the most desirable.

Three pilots used the NVG simulators. Two of these aviators stated that the simulators did provide some help in adjusting to both the weight and the narrower field-of-view. These were the only features of the simulators which helped them adjust to the AN/PVS-5's.

SUMMARY

For the NOE flight segment, the NVG's were associated with slightly lower flight altitudes. As a function of reduced altitude, mean airspeeds were slower and control activity higher due to a greater obstacle avoidance requirement. The data also indicate that the 40° goggles were associated with smoother, more gradual control movements than were the 60° goggles. It was hypothesized that this may have been a function of the resolution differences between these goggles.

During Low Level flight the 40° and 40°b goggles were again associated with lower mean altitude relative to the unaided eye. This situation did not hold for the 60° FOV. Again, as with the NOE flight, the

goggles were associated with slower airspeeds. Between the 40° and unaided eye, the data indicated a bit more heading variability.

For the 360° Left Pedal Turn maneuver, the goggles were in general associated with slightly more variability and error in altitude and difficulty in holding longitudinal position.

In the Forward Hover maneuver, the aviator performance and the aircraft system output were quite similar for all visual sets while the unaided eye condition exhibited more cyclic and pedal activity.

The dominant measure separating the visual conditions of the 25 Foot Hover maneuver was the average absolute error along the longitudinal axis or horizontal displacement. Data on this variable indicate that the 40° and 40°b goggles were associated with better position maintenance over the starting point relative to the 60° goggle and unaided eye. It should also be pointed out that all three goggle conditions exhibited better drift control than the unaided eye condition.

For the Hover Rearward maneuver the errors in altitude scores were the most discriminating among the four visual sets. The data for these two parameters indicate that the 40° and 40°b goggle conditions hovered rearward at lower mean altitudes, thus were closer to the command altitude of five feet AGL than the 60° goggle and unaided eye conditions. The 40° and 40°b conditions also exhibited slightly less total absolute error from the command altitude than did the 60° goggle and unaided eye conditions.

CONCLUSIONS

Based on the results contained in this report, experience gained in conducting this effort, and the findings of others, the following conclusions appear warranted:

1. Available illumination is a critical factor when using NVG's.

2. Intermittent cloud cover when supplemental illumination is not used creates problems when using current generation NVG's.

3. There are illumination levels compatible with the NVG's at which there is in general an increased capability provided over the unaided eye.

4. Further research must be conducted to determine the illuminance levels where the goggles provide increased capability and where they do not.

5. It would appear that to conduct NVG training (without simulators), a training area will need to be illuminated to some NVG compatible level. If this is not done, training will be dictated in large measure by moon phases and prevailing cloud cover.

6. Depth perception is influenced when flying with the goggles and further research evaluating this influence is necessary.

7. The higher resolution 40° FOV goggle was in general favored over the 60° FOV poorer resolution goggle.

8. Bifocals (30% cut) which permit inside capability without manual refocus are preferred for enroute work.

9. Bifocals (30% cut) are not preferred when performing maneuvers close to the terrain. This is probably due to the FOV reduction precipitated by the bifocal.

10. Research should be conducted with smaller than 30% cuts to determine their efficiency and acceptance.

11. Bifocal goggles should be examined in light of copilot/navigator performance requirements.

12. Maps can and have been made which are goggle compatible.

13. Aircraft and cockpit lighting must and can be made compatible with NVG's.

14. NVG's can provide the pilot, in some circumstances, with increased staying power when operating in intermittent light sources because of their light compensation capability. The unaided, dark adapted eye exposed to the same light would be adversely affected.

15. Modifications in mounting the NVG can be made and should be made to shift current weight bearing surfaces and c.g.

16. Efforts should be made to reduce goggle weight for safety considerations.

17. Safety procedures must be established and adhered to when using the NVG's.

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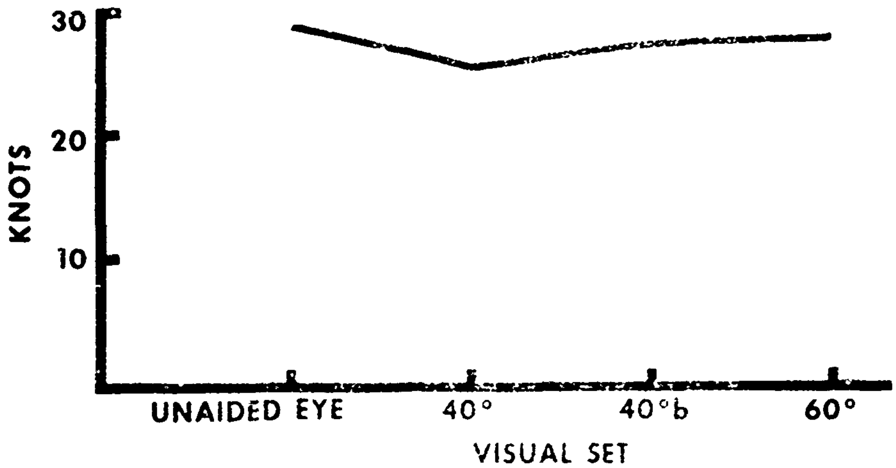
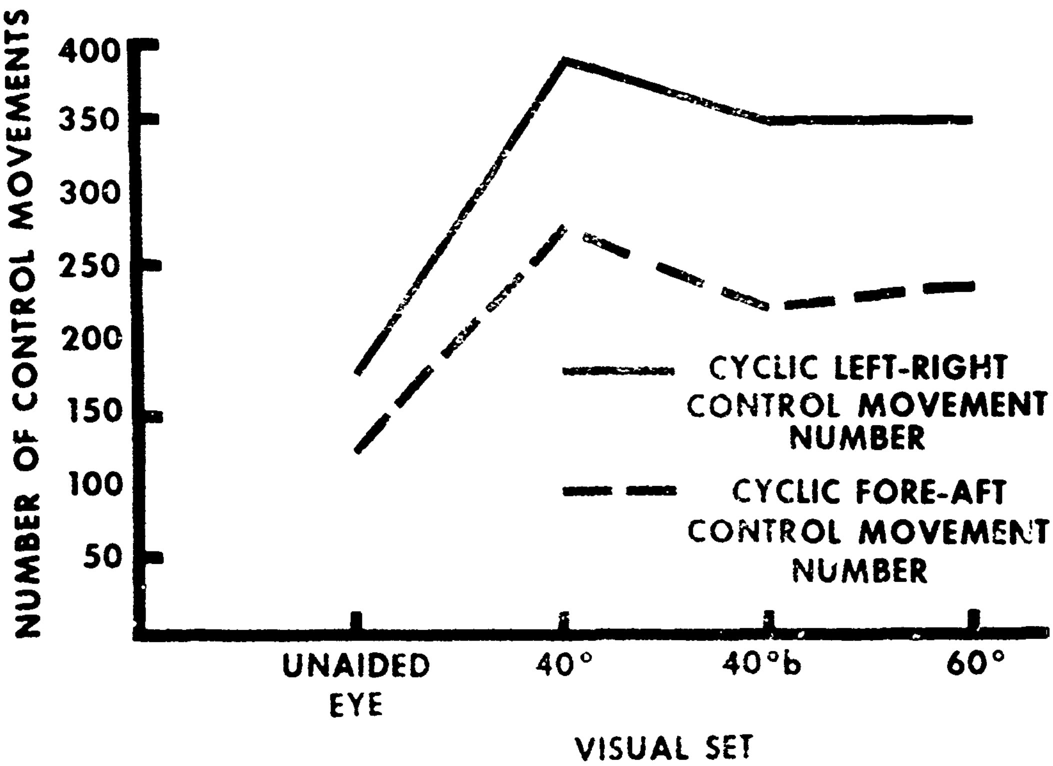
APPENDIX A

Figures for Univariate Data



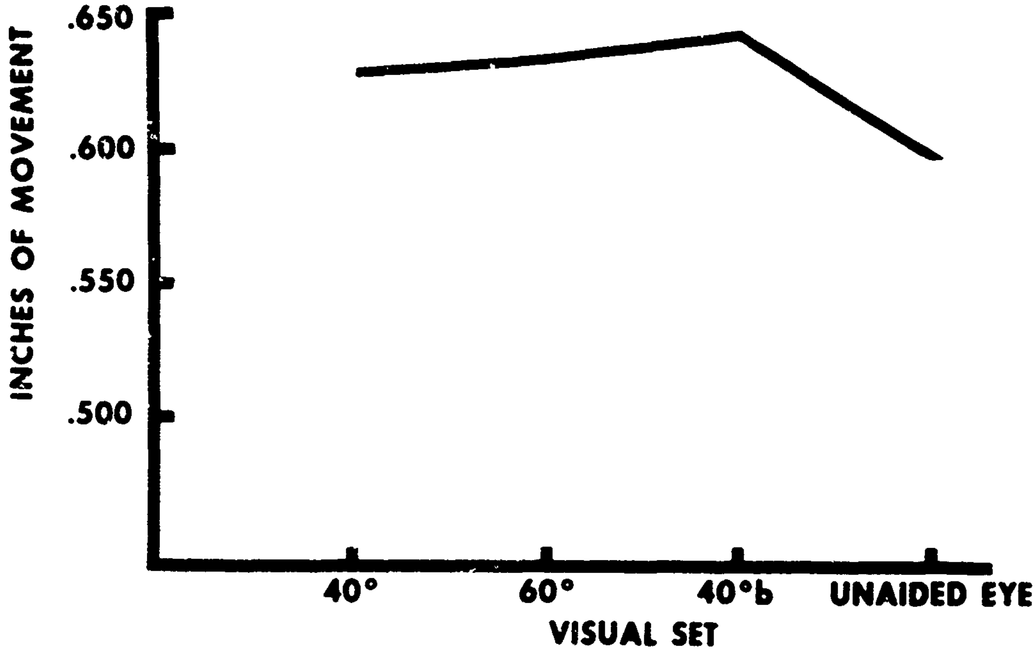
NOE MEAN AIRSPEED IN KNOTS

FIGURE 2

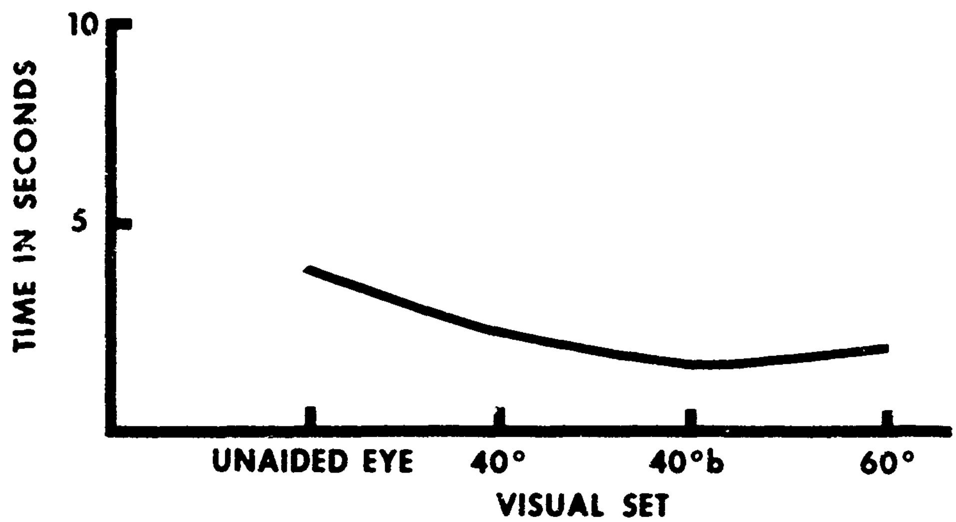


NOE CYCLIC FORE - AFT AND LEFT - RIGHT CONTROL MOVEMENT NUMBER

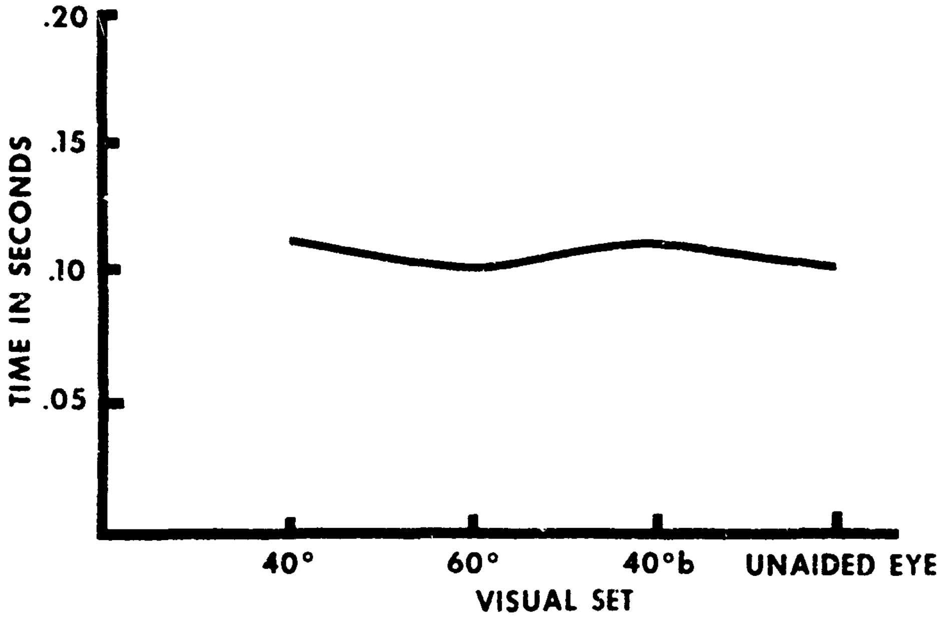
FIGURE 3



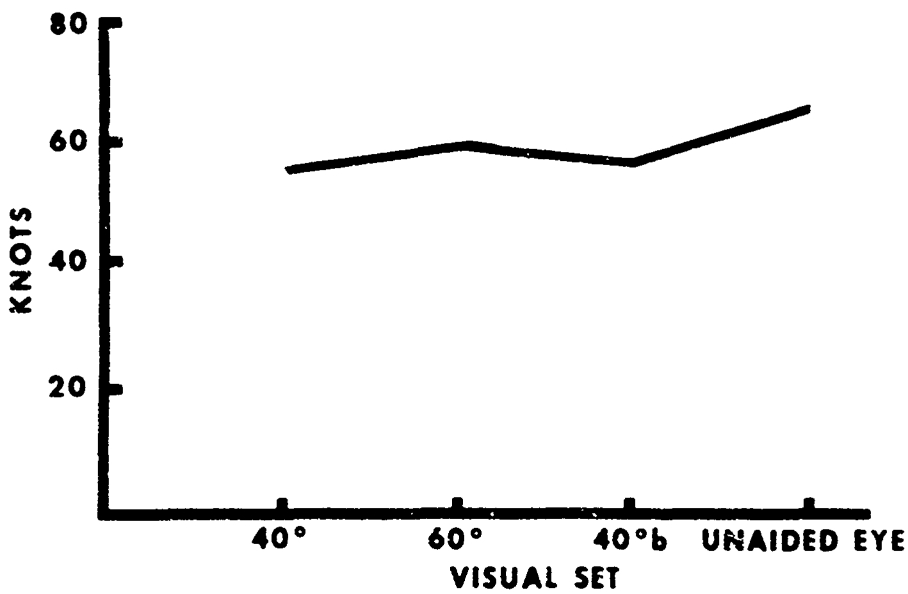
NOE CYCLIC LEFT - RIGHT
ABSOLUTE CONTROL MOVEMENT MAGNITUDE
FIGURE 4



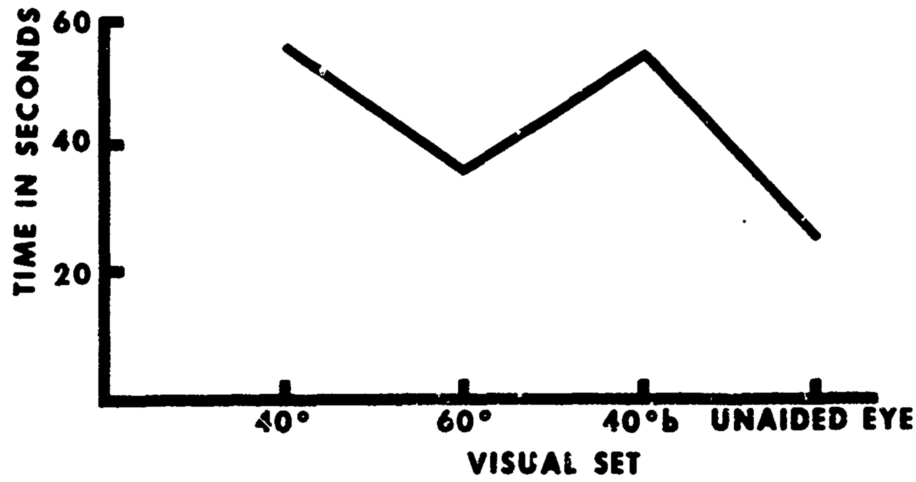
NOE CYCLIC LEFT - RIGHT
CONTROL STEADY STATE MEAN TIME
FIGURE 5



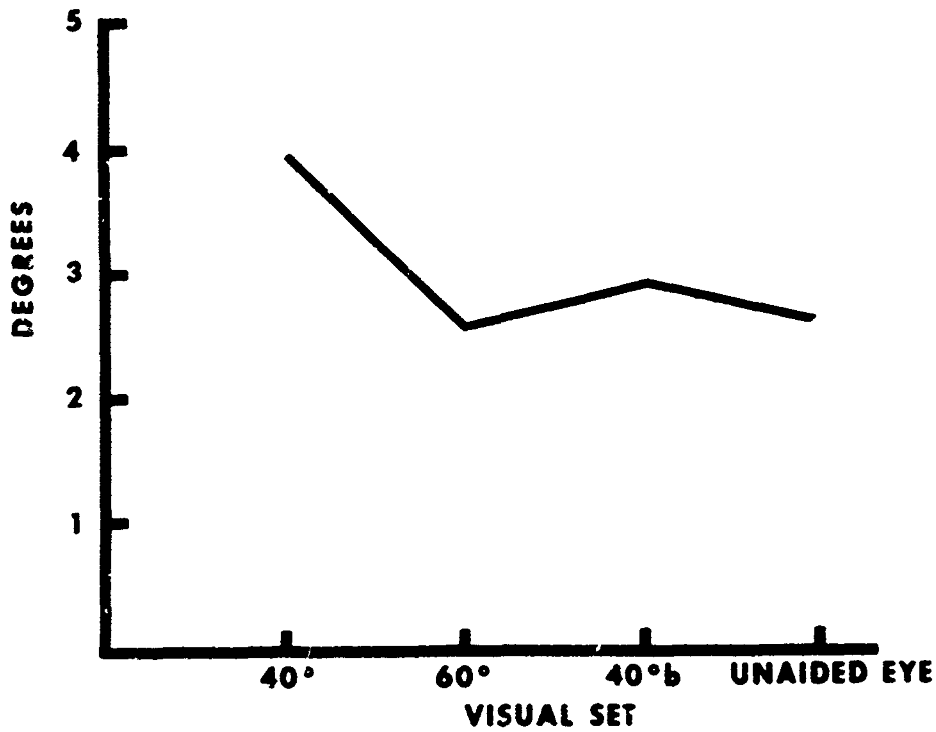
NOE CYCLIC LEFT - RIGHT
CONTROL MOVEMENT MEAN TIME
FIGURE 6



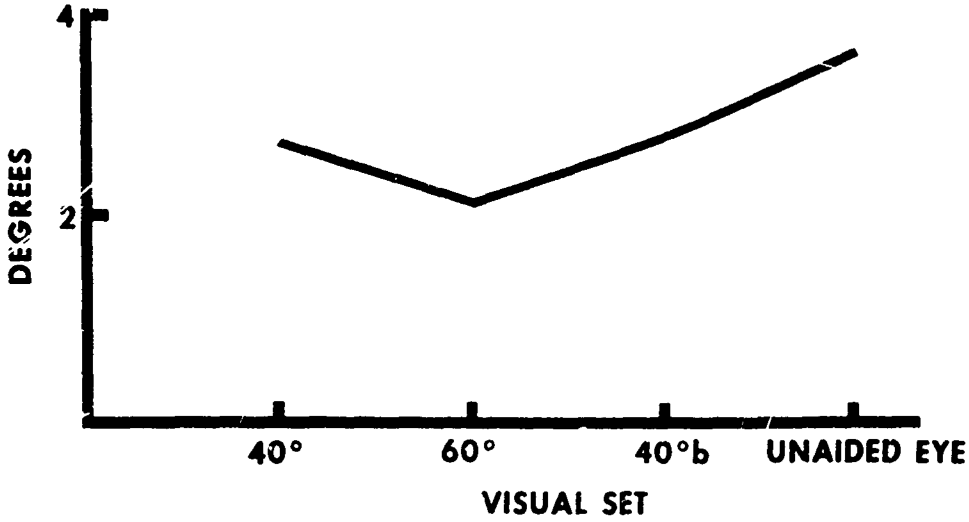
LOW LEVEL MEAN AIRSPEED
FIGURE 7



LOW LEVEL CYCLIC LEFT - RIGHT CONTROL STEADY STATE MEAN TIME
FIGURE 8

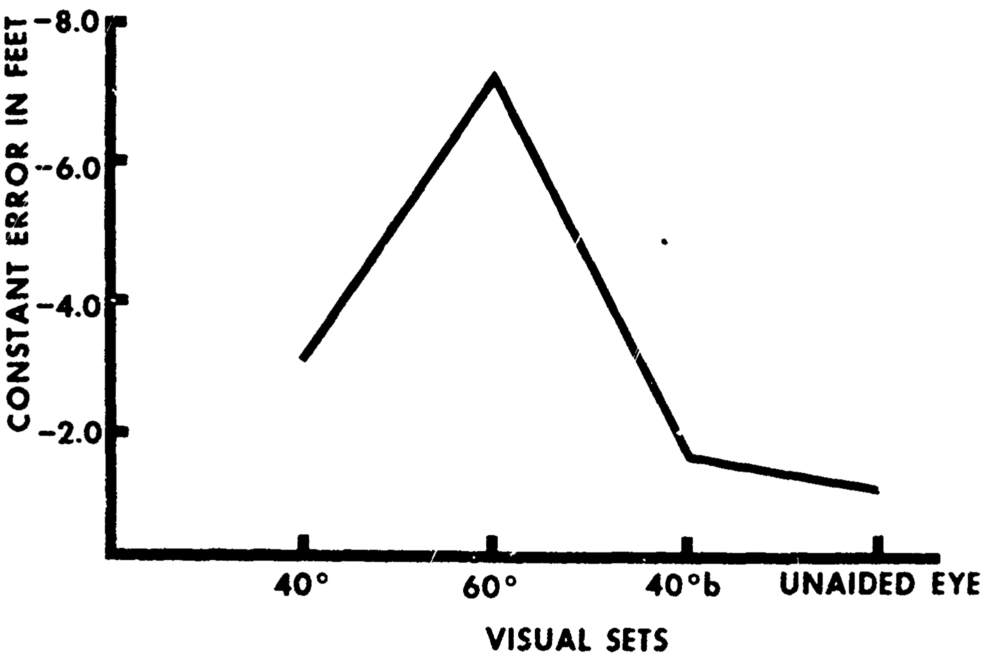


LOW LEVEL STANDARD DEVIATION - HEADING
FIGURE 9



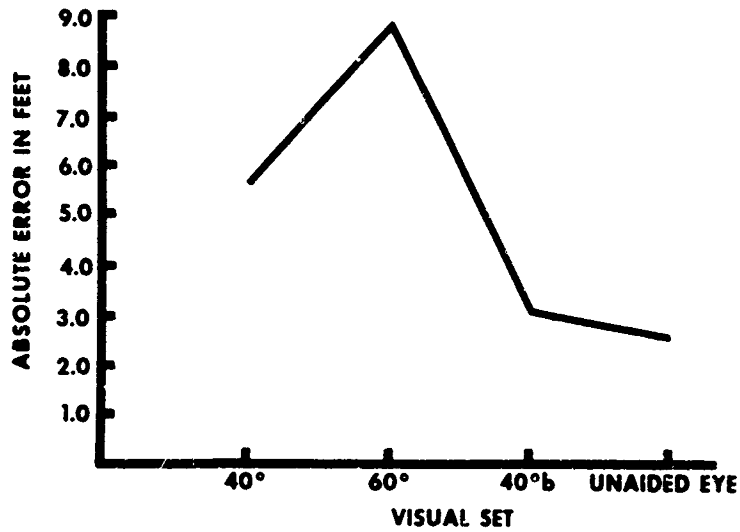
360° LEFT PEDAL TURN MEAN PITCH ANGLE IN DEGREES

FIGURE 10



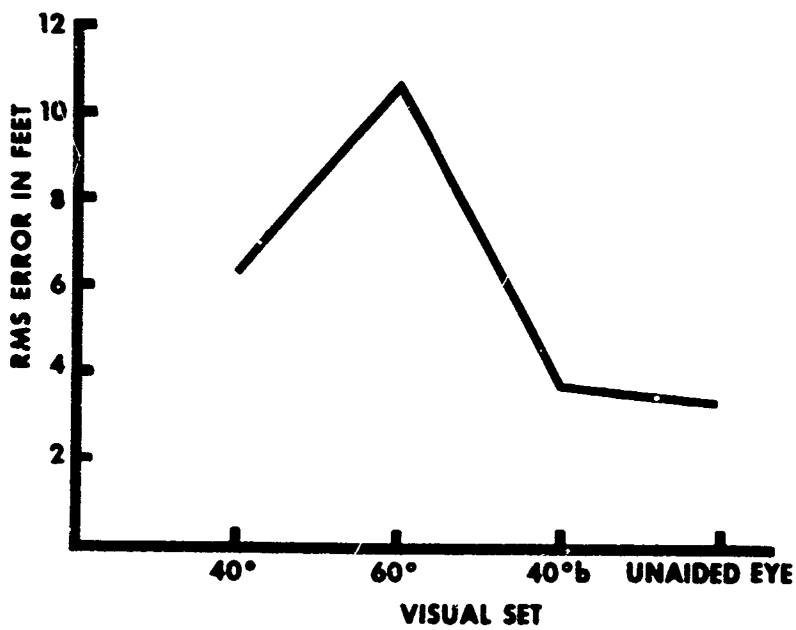
360° LEFT PEDAL TURN RADAR ALTITUDE AVERAGE CONSTANT ERROR

FIGURE 11



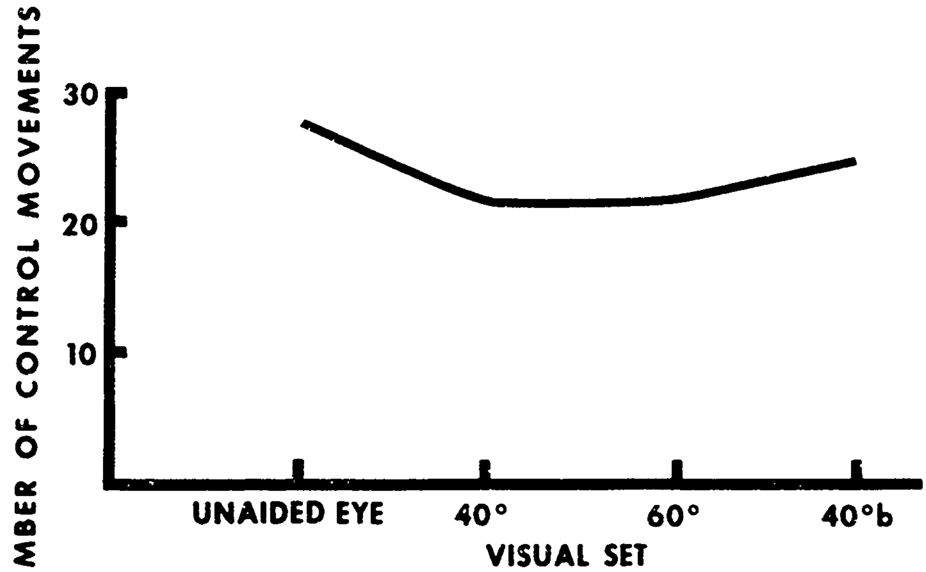
360° LEFT PEDAL TURN RADAR ALTITUDE AVERAGE ABSOLUTE ERROR

FIGURE 12

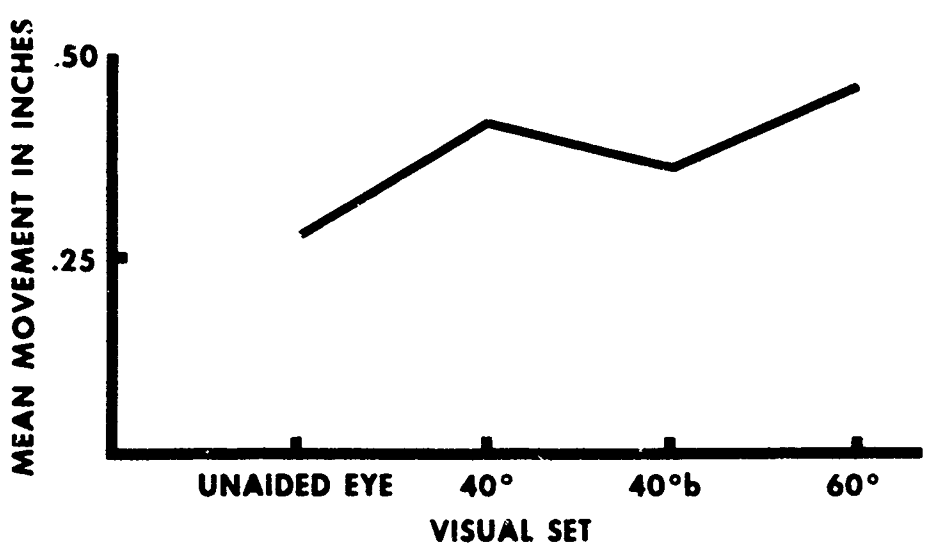


360° LEFT PEDAL TURN RADAR ALTITUDE ROOT MEAN SQUARE ERROR

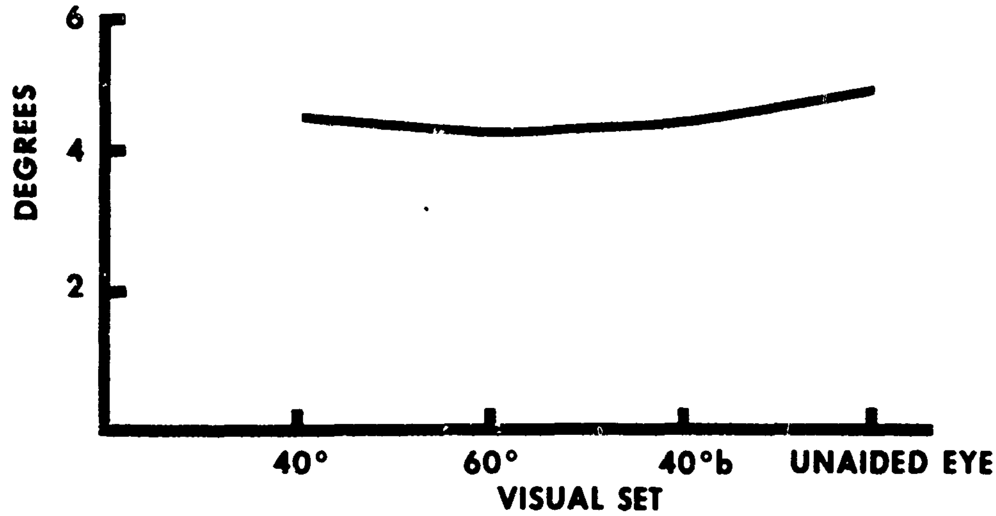
FIGURE 13



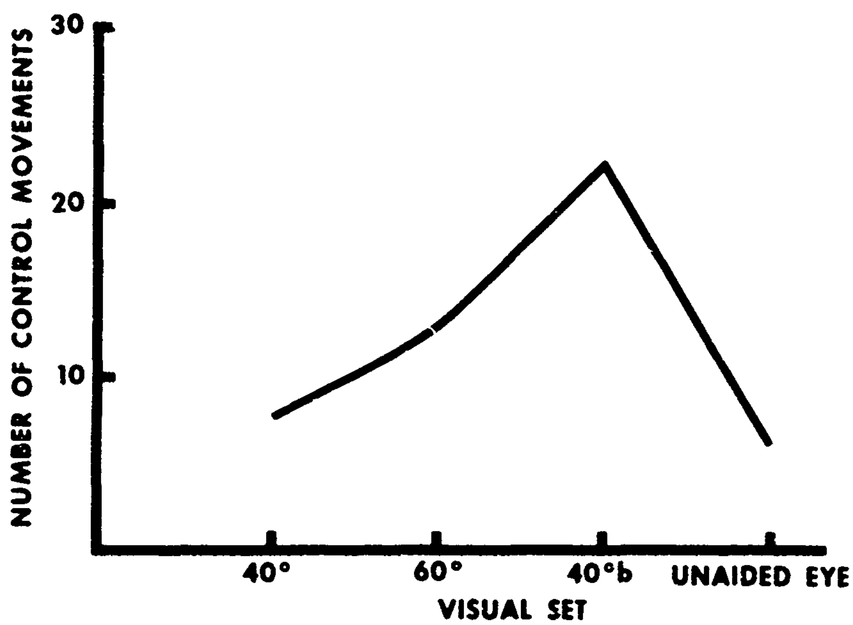
HOVER FORWARD CYCLIC FORE - AFT CONTROL MOVEMENT NUMBER
FIGURE 14



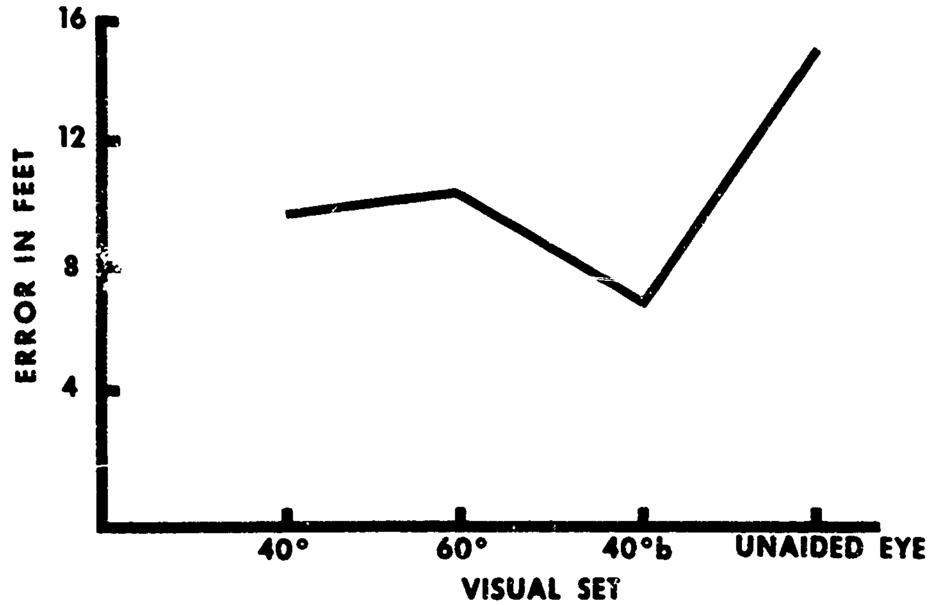
HOVER FORWARD PEDAL ABSOLUTE CONTROL MOVEMENT MAGNITUDE
FIGURE 15



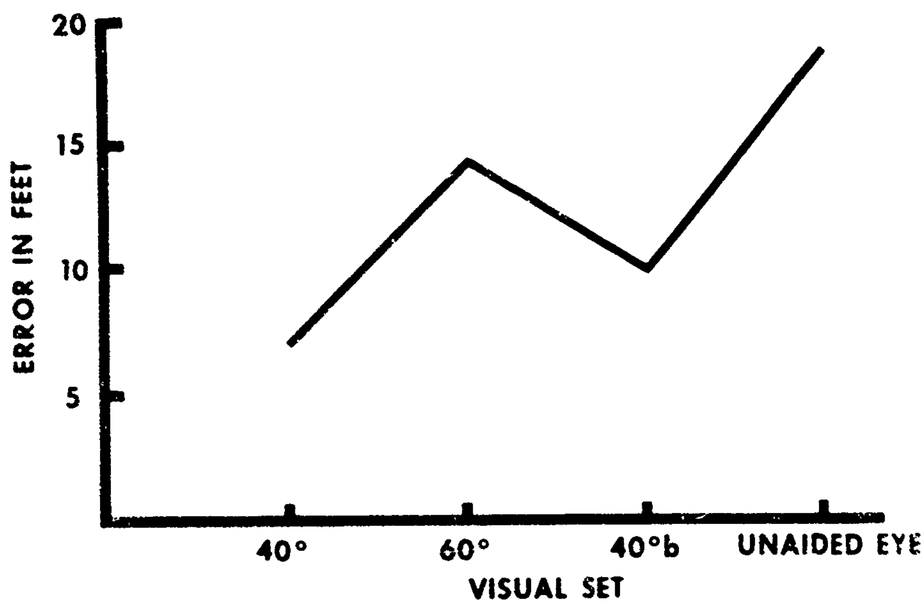
25 FOOT HOVER MEAN
PITCH ANGLE IN DEGREES
FIGURE 16



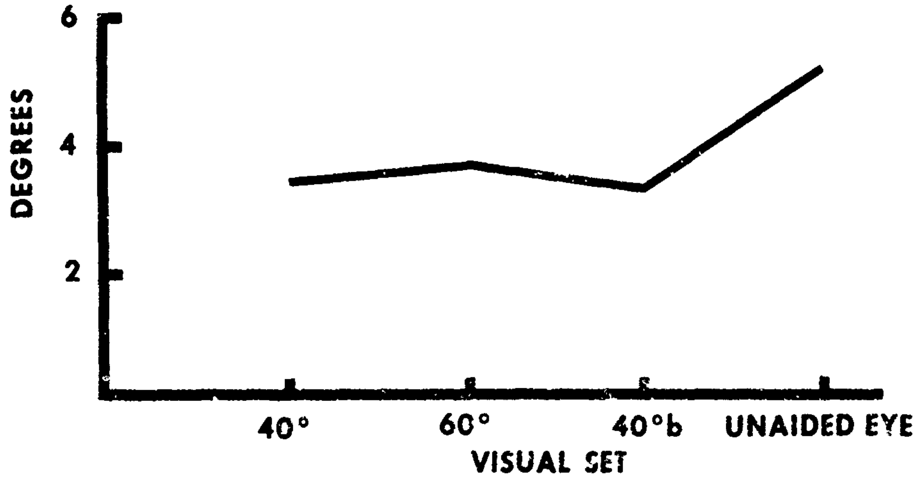
25 FOOT HOVER CYCLIC LEFT - RIGHT
CONTROL MOVEMENT NUMBER
FIGURE 17



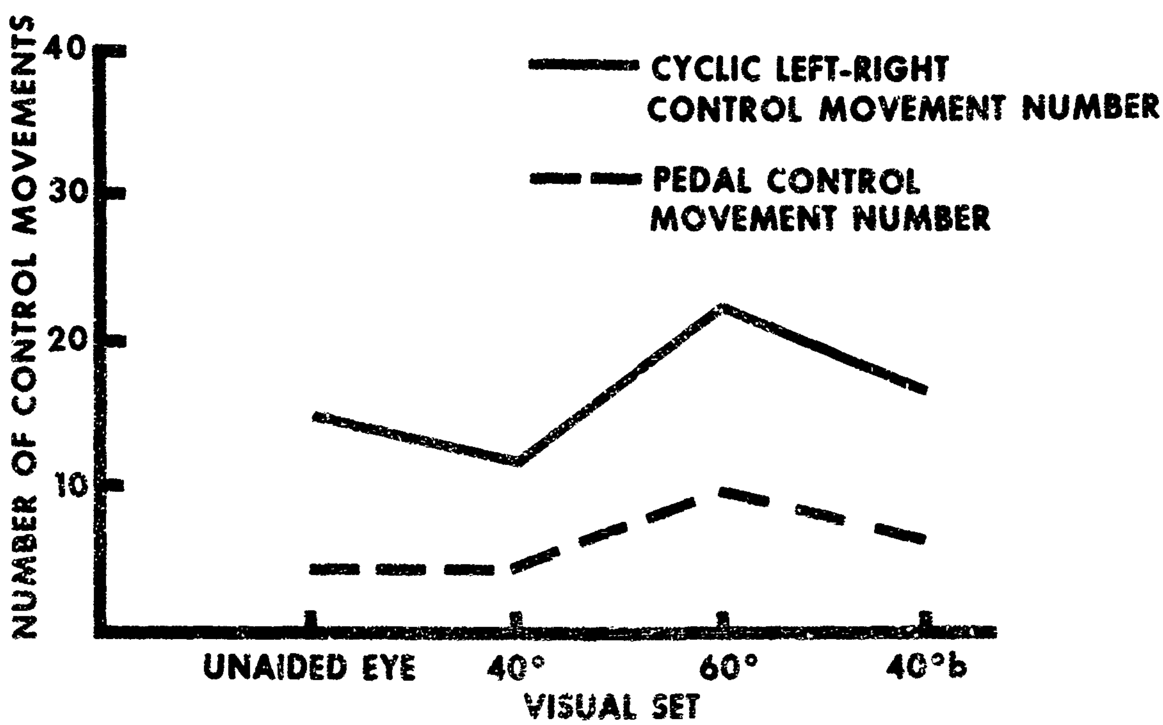
25 FOOT HOVER AVERAGE ABSOLUTE ERROR IN X
FIGURE 18



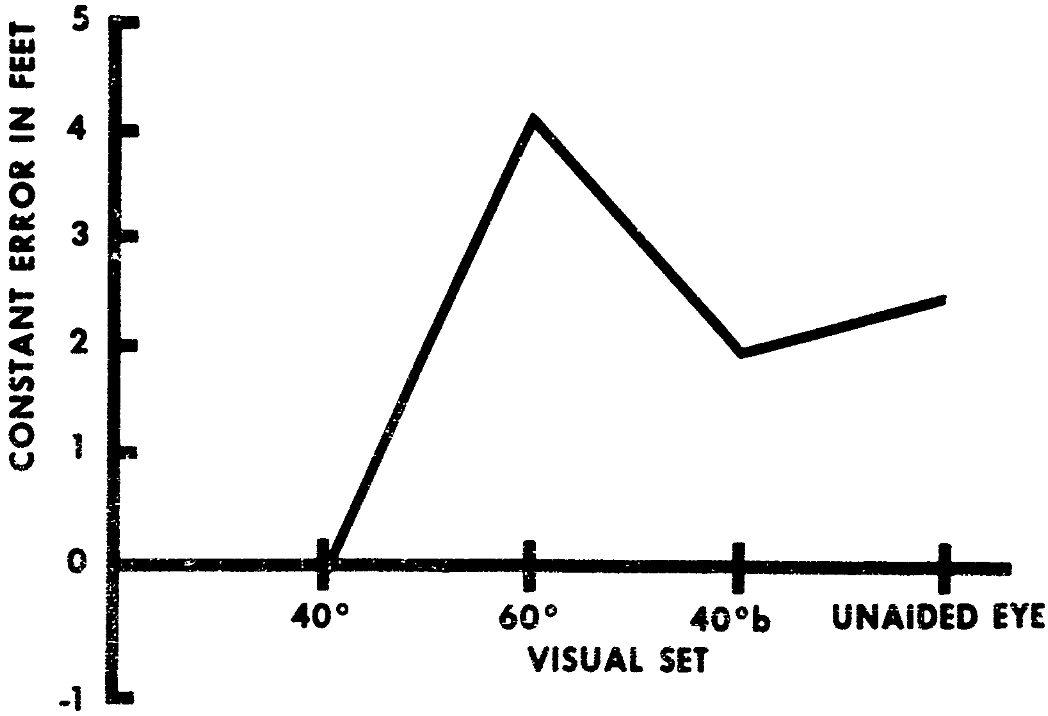
25 FOOT HOVER RMS ERROR IN X
FIGURE 19



HOVER REARWARD MEAN PITCH ANGLE IN DEGREES
FIGURE 20



HOVER REARWARD CYCLIC LEFT - RIGHT
AND PEDAL CONTROL MOVEMENT NUMBER
FIGURE 21



HOVER REARWARD RADAR
ALTITUDE AVERAGE CONSTANT ERROR
FIGURE 22

Since Schori and Tindell's transformation technique for repeated measures was utilized on conventional multiple discriminant analysis programs, some corrections should be made to the statistical output of these programs. These corrections apply to three areas. First in the univariate output, the degrees of freedom (df) for the denominator should be reduced by n-1 resulting in degrees of freedom of 12 instead of 16 for the low level and NOE flight segments and 15 instead of 20 for the 360° left pedal turn, hover forward, 25-foot hover, and hover rearward maneuvers. As a consequence of these reduced degrees of freedom, the absolute values of the univariate F should be reduced by 25%.

The second matter of note is that the Wilks Lambda values, though not reported, were computed and found to exceed the .05 significance level.

The third point of consideration is that the chi-square statistic for significance testing of the individual roots should also be reduced by n-1, resulting in a reduction of the listed chi-square statistics by 32%.

These points are of statistical importance but they do not change the relationship between the variables examined. Additionally, they do not alter the interpretation of the variables' contribution to the flight performance or the overall interpretation of the flight performance.

In all cases where a reduction in the absolute value of a test statistic is warranted, this reduction did not place the statistic outside the preestablished significance point.